Abstract Title Page

Title: Designing Technology to Impact Classroom Practice: How Technology Design for Learning Can Support Both Students and Teachers

Authors and Affiliations:

Maria Mendiburo
The Carnegie Foundation

Laura K. Williams
Department of Special Education
Vanderbilt University

Brian Sulcer
Department of Special Education
Vanderbilt University

Ted Hasselbring
Department of Special Education
Vanderbilt University

Abstract Body

Background and Context:

Many decades of research shows that integrating manipulatives into instruction about basic fractions concepts improves students' conceptual understanding of fractions (Behr, Cramer, Harel, Lesh, & Post, 2002). Research also shows that interactive virtual representations of fractions have a stronger impact on student learning than static virtual representations (Feenstra, Aleven, Rummel, Rau, & Taatgen, 2011). In the United States, the Common Core Standards for Mathematics, which were released in 2010 and have since been adopted by 45 states, places heavy emphasis on students being able to support and justify their answers to problems with visual models. Therefore, it is not surprising that virtual resources such as the National Library of Virtual Manipulatives, the National Council of Teachers of Mathematics Illuminations website (NCTM, 2000), and Drexel University's Math Tools website (Math Forum @ Drexel, 2003) are becoming increasingly more popular with teachers. These free resources each contain hundreds applications and activities designed to enhance K-12 mathematics instruction. However, to our knowledge, the applications contained in these resources are not adaptive, have little embedded support for learning, and do not provide teachers with analytics that can inform pedagogical decisions, limiting their potential utility in classroom contexts.

The research literature about virtual manipulatives includes several investigations about the most effective forms of scaffolding and feedback that can be embedded in intelligent tutoring systems to support student learning (e.g. Rau, Aleven, & Rummel, 2013; Stampfer, Long, Aleven, & Koedinger, 2011). However, the majority of this research focuses on students primarily working one-on-one with a computer system, which is suboptimal for a traditional classroom environment and fails to capitalize on the skill and experience of teachers. We developed the HALF (Helping At-risk students Learn Fractions) intervention program in response to the need for a classroom-based instructional program that integrates the potential of technology-based instruction with support for teachers and the classroom environment. The HALF project began in 2010, and the long-term goal of the project is to develop a complete, manipulative-based fractions intervention program that can be effectively implemented in mixed-ability classes.

The HALF intervention uses the developmental and cognitive theories of the Zone of Proximal Development (ZPD) and the Classroom Learning Zone (CLZ) to optimize instruction. The theory behind the ZPD (Vygotsky, 1978) is that an individual learns the most when the skill or knowledge required for a task is proportional to the individual's current knowledge or ability. If the task is too relatively too easy, there is little for the individual to learn; if the task is too hard, the individual does not have a sufficient foundation and cannot be successful. The theory of CLZ (Murata & Fuson, 2006) is a way for teachers to enact the ZPD framework for an entire class of students. Although a class may have 20-35 students, when students begin learning new content, the majority of students use 3 to 6 solution strategies to solve problems related to that content. The majority of students who fail to master the content on the first try are likely to make one of a small set of predictable errors. The CLZ allows teachers to target instruction to their students' current knowledge within a larger classroom setting. The HALF intervention uses the ITS to automatically adjust the level of cognitive demand students experience in order to align with each student's ZPD and to provide information to teachers in aligning group instruction to the students' CLZs.

Focus of Research:

In this paper, we discuss a portion of the design research process of developing an intelligent tutoring system (ITS) for classroom use. The goal of this ITS is to simultaneously provide automated support for student learning and generate diagnostic information for teachers that can lead directly to actionable recommendations for pedagogy and classroom practice. We focus here on two goals of the design process: first, on implementing automated supports within the ITS to optimize individual learning within the intervention; and second, on exploring teachers' use of the information provided by the system in order to help them use this information most effectively.

Intervention:

The HALF intervention program is a mixed-methods fractions instructional program designed for use in mixed-ability classrooms by 5th and 6th grade students. The HALF program uses an instructional model that combines technology-based instruction using an intelligent tutoring system on iPads with teacher-led instruction in the classroom. This instructional model is based on that of READ 180, a highly successful intervention program for struggling readers (Slavin, Cheung, Groff, & Lake, 2008). Like READ 180, the HALF program uses a rotational model within each instructional period. Students begin each period with a brief teacher-led whole-class discussion on a grade-appropriate fractions topic. Students then rotate through three activities: individual work with the ITS, in which students can work at their own pace and at a level appropriate to their individual ZPD; teacher-led small group work on a lesson designed to either strengthen foundational fractions knowledge or apply existing fractions knowledge in new applications; and review and fluency practice on the iPad in the form of quizzes and games. The HALF intervention places a heavy emphasis on the use of virtual manipulatives, i.e. manipulatives and model-building tools used on the iPad, to improve students' conceptual understanding of fractions concepts. Students are taught to use models to help reason about fractions in the multiple forms of representation shown in the Lesh Translation Model (Figure 1; Lesh, Cramer, Doerr, Post, & Zawojewski, 2003).

The uniting factor in the HALF intervention is the technology system. Each student's daily progress and performance in the ITS is available to the teacher, both in real-time and in aggregate at the end of the day, and this information is then used to suggest small group assignments and lesson plans for the next day. This allows the student groupings to change on a daily basis in response to students' immediate instructional needs and facilitates in-class instructional differentiation by the teacher.

Setting and Participants:

We conducted a two week (10 school day) test of the HALF intervention program at a public charter middle school in Tennessee. The school included three 5th grade (ages 10-11) mathematics classes that were taught by one teacher and three 6th grade (ages 11-12) mathematics classes that were taught by a second teacher. All 5th and 6th grade students in these classes were eligible to participate in the study. The total sample included 115 students. Table 1 shows the demographics of this sample by grade and treatment condition.

Two teachers were involved during the course of this study. Teacher A was a novice teacher who had previously taught the mathematics, reading, and language classes for a small group of students identified as English-Language Learners (ELL). She had little experience in teaching math or in formal mathematics pedagogy. In this study, she taught all three 5th grade math classes. Teacher B was an experienced (10+ years) middle-school mathematics teacher with extensive training in mathematics pedagogy. She taught all three 6^{th} grade math classes in this study. She had also taught the same group of students the previous school year as 5^{th} graders.

Research Design:

Teachers implemented the HALF intervention program in two classes for each grade level (treatment classes). For the control condition, teachers implemented lessons from the Fractions B module of a widely-used commercial intervention program by Scholastic called Do the Math for the third class in each grade level. The teachers who implemented these programs received training from HALF researchers and Scholastic representatives prior to the first day of the study. HALF researchers met with the teachers on a daily basis during the study to review lesson plans and discuss pedagogical strategies for HALF and for Do the Math and to review data generated by the HALF computer-based tutorial system. Teachers also received direct support from HALF researchers during instructional time for the first week of teaching in all classes. During the second week of the study, HALF researchers observed all classes, but the teachers received no direct support during instructional time.

Data Collection and Analysis:

In order to measure student learning gains over the course of the intervention, students completed two pre-tests prior to the first day of the study and then completed the same two tests after the study. One 25-question test was drawn directly from the Do the Math curriculum and is regularly used to measure student learning in classrooms that implement the commercial Do the Math curriculum. The second test included 30-questions drawn from a test bank of assessment items that we developed and tested in other research related to the HALF project (Mendiburo, Williams, Henson, & Hasselbring, 2013). All students, regardless of treatment condition, completed the both assessments at both times, both for comparability between conditions and to help ensure that any observed learning gains exist regardless of the assessment used. The results were analyzed to determine learning gains within grade and treatment condition and to compare the learning gains between the treatment and control classes by grade.

Due to the often exploratory nature of the design research process (Design-Based Research Collective, 2003), we also collected qualitative data in the form of classroom observation and discussions with teachers. Researchers met with teachers on a daily basis in support of implementing the HALF and Do the Math programs. In addition to the researchers answering implementation questions and helping to ensure the two programs were being enacted correctly, teachers were asked for their thoughts on using each curriculum, issues they struggled with, and ways that the technology could be improved to better support teachers.

Findings / Outcomes:

We found that the HALF intervention program led to strong learning gains for the students who participated in the two-week intervention. Effect sizes for the gains made by students in the treatment condition ranged from $d = .14$ (HALF assessment scores for 6th grade treatment classes) to $d = .82$ (Do the Math assessment scores for 5th grade treatment classes). The full set of these results is shown in Table 2. The learning effects for students in the treatment classes were also just as large as the learning effects for students in the control classes (p = ns for both grades and both assessments).We hope to continue making improvements to the system that will eventually result in larger learning gains than existing curricula, but these results show that the current version of the HALF intervention program is already producing the same learning gains as a fully developed and widely used commercial intervention. Additionally, a more general examination of the path students took within lessons showed that the automated supports were successful in helping to move struggling students to correct misconceptions and move through the stages present in each lesson in the ITS (Figure 2).

Our results also showed that the system positively impacted teachers' ability to enact CLZ during small group instruction. Teachers responded positively to the standardization of the content of the tutorials into categories and the consistency of the scaffolds given to students across different stages of the tutorials. During their daily meetings, the teachers and the researchers engaged in multiple high-level discussions about students patterns of movement through the stages of the computer-based tutorial and the possible pedagogical strategies that the teachers could employ during small group instruction to address misconceptions. In contrast, teachers questions about implementing the Do the Math curriculum were typically procedural and focused on aspects of the curriculum in general. For example, the 5th grade teacher asked HALF researchers to go over the rules of one of the game she needed to implement in the control class during the next class period and the 6th grade teacher asked HALF researchers to assess the pace at which she was completing the Do the Math lessons. In a follow-up interview after the conclusion of the study, the 6th grade teacher made the following comment about her experiences implementing the Do the Math curriculum in comparison to the HALF intervention program:

> The fact that I had to sit down for several hours and grade all these workbooks [from the control condition] was very daunting compared to “Here, here's your grades for the day." I was like “Yes!" ... I'd rather spend time looking at the data and seeing what that says and having conversations like we had about “You know, this kid didn't do really well on the pre-test, maybe you can find out more."

Conclusions:

The results of this study suggest that the HALF intervention program has a similar positive impact on student learning as a fully developed commercial curriculum; student learning is at least as good as in an existing, widely used curriculum. We also found that the data produced by the current set of scaffolds and learning supports embedded in the computer-based tutorial system about students interactions with the virtual manipulatives have a positive impact on teachers' ability to enact the theory of classroom learning zones. Teachers reported greater interaction with their students’ learning progress and had more satisfaction with the instructional progress under HALF. The current stage of development of the HALF intervention program is demonstrating success in supporting student learning with virtual manipulatives and multiple forms of representation and in supporting teachers’ use of data to differentiate instruction.

While this study did demonstrate success of the HALF system, one way that it can yet be improved is to make the system less dependent on the presence of experts in the system and the content (e.g. the research team). More of the recommendations delivered to teachers need to be automated in order to move the project towards sustainable use in regular, non-research, instruction, and we plan to work towards this goal in future studies.

Appendices

Appendix A. References

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Appendix B. Tables and Figures

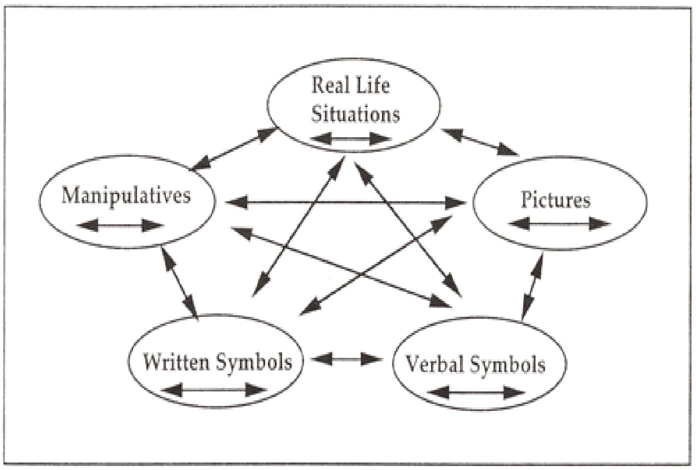

Figure 1. The Lesh Translation Model, demonstrating the relationship between different forms of representation of fractions.

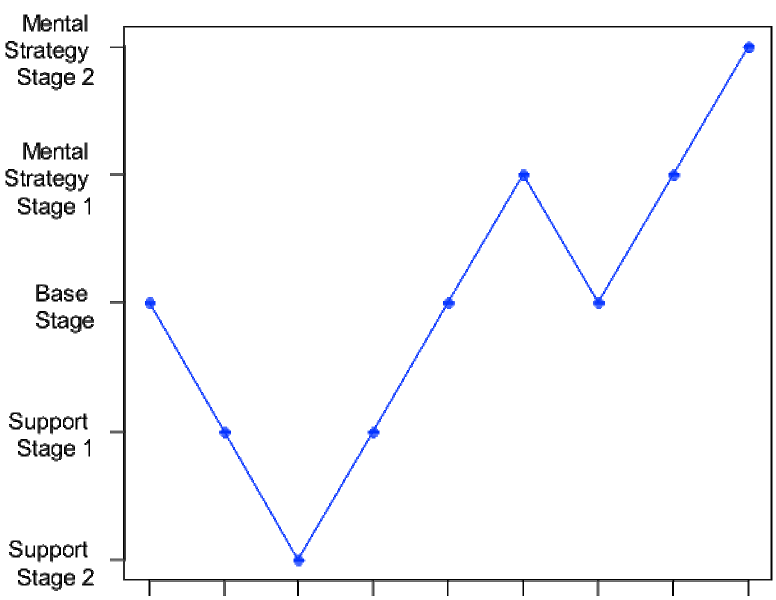

Figure 2. Sample depiction of how the automated supports in the intelligent tutoring system help a student to move through the system. The student entered at the base level and initially struggled, moving through the two additional learning support stages. The embedded supports helped the student to correct her misconceptions and succeed, moving through the practice stages and transition into a new content area. Had the student continued to cycle, the pattern would have showed her as unable to move beyond the support stages and would have alerted the teacher to intervene.

Table 1
Student Sample Demographics by Grade and Treatment Condition

Group		*N*	% Male	% White	%FRL	%ELL	%SPED
5th Grade							
	Control	15	53.33	13.33	100	0	0.07
	Treatment	35	60	40	85.71	14.29	11.43
6th Grade							
	Control	21	61.91	19.05	90.48	0	0
	Treatment	44	47.73	13.64	88.64	15.91	15.91

Table 2
Raw Score Sample Statistics and Effect Sizes Within Condition

	Pretest (raw scores)		Posttest (raw scores)			
Group	*M*	*SD*	*M*	*SD*	Gain	ES (*d*)
HALF Assessment						
5th Grade						
Control	56.44	12.75	59.11	13.71	2.67	0.19
Treatment	57.52	14.54	63.91	16.08	6.38	0.41
6th Grade						
Control	67.94	20.15	72.06	17.43	4.12	0.21
Treatment	62.73	21.35	65.76	22.61	3.03	0.14
Do the Math Assessment						
5th Grade						
Control	51.46	20.83	70.13	12.64	18.67	1.05
Treatment	50.06	20.45	66.29	18.47	16.23	0.82
6th Grade						
Control	64.57	23.37	72.19	18.82	7.62	0.35
Treatment	53.72	25.78	63.82	25.18	10.09	0.39