THE EFFECT OF AN INTELLIGENT TUTOR ON MATH PROBLEM-SOLVING OF STUDENTS WITH LEARNING DISABILITIES

Xiaojun Ma[1],Yan Ping Xin[1], Ron Tzur[2], Luo Si[1],
Xuan Yang[1], Joo Y. Park[1], Jia Liu[1], Rui Ding[1]

[1]Purdue University, [2]UC-Denver

Reform-based math instruction calls for students' construction of conceptual understanding, solving challenging problems and explanation of reasoning. However, existing literature shows that students with learning disabilities (LD) easily get lost in reform-based instruction. As an outcome of collaborative work between math education and special education in instructing students with LD, we've developed an intelligent tutor (PGBM-COMPS) to nurture multiplicative reasoning of students with LD. The intelligent tutor dynamically models individual student's evolving conceptions and recommends tasks to promote her/his advancement to a higher level in the learning trajectory and solve complex word problems using mathematical model equations. This study evaluated the effect of this intelligent tutor on improving multiplicative reasoning and problem solving of students with LD.

INTRODUCTION

In line with the reform in math education, the Common Core State Standards for Mathematics (CCSSM) emphasizes conceptual understanding in problem solving, mathematical modeling, higher order thinking and reasoning, and algebra readiness (NGA & CCSSO, 2012). It also promotes student-centered learning as well as the use of technology.

New standards also stress "opportunity to learn" (OTL) for students. OTL refers to all students, including those with special needs or learning difficulties, have equal opportunity to get access to learning resources and meet the same high standards. According to National Council of Teacher of Mathematics (NCTM) Standards (2000), students with LD and without LD should be given the equal opportunities to solve meaningful and complicated mathematics problems. However, students with Learning Disabilities (LD) lag behind their peers without LD at least two grades levels (Wagner, 1995). Even though students with LD showed various problems in mathematics learning, they share some common characteristics (Goldman, 1989; Rivera, 1997). Students with LD are likely cognitively disadvantaged, particularly in the area of working memory (Richard, 2012), which lead to poor performance in acquiring math facts and solving mathematics problems (Kroesbergen & Van Luit, 2003). Due to these problems, students with LD often show difficulties in connecting the knowledge they have learned with new knowledge and generating new knowledge (Kroesbergen & Van Luit, 2003). Moreover, students with LD tend to have attention problems, which

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are often regarded as short attention span (Stevens, 1996; National Association of Special Education Teachers, n.d.). Students with LD who have a short attention span will easily get distracted if they see something, hear something, smell something or feel something and cannot focus on a task for more than several seconds (Stevens; National Association of Special Education Teachers). Facing with these disadvantages, students with LD have difficulties to fully get involved in mathematics problem solving, particularly in reform-based instructional environment (Miller & Hudson, 2007). Besides this, existing literature shows that students with learning disabilities/difficulties easily get lost in reform-based instruction and "seemed to disappear during whole class discussions" (Baxter, Woodward, and Olson, 2001, p. 545).

Given the characteristics of students with LD, new standards students with LD need to meet and today's inclusive classrooms, it is needed to develop intervention program to provide every student with optimal opportunities to learn and therefore meet the new standards. Computer-assisted instruction (CAI) may help teachers in meeting individual student's needs in the inclusive classroom. In fact, according to the National Council of Teachers of Mathematics Standards (NCTM, 2000), the Mathematical Science Education Board (1991), as well as the Mathematical Association of America (1991), current mathematics reform encourages the use of computer technologies for both teachers and students in the classroom.

The purpose of this study was to explore the effect of an intelligent tutor (PGBM-COMPS) on nurturing multiplicative reasoning of elementary students with LD. The specific research questions were: (1) Was there a functional relationship between the intervention delivered by the PGBM-COMPS tutor and students' performance on a multiplicative reasoning and problem solving criterion test; (2) did students improve their performance on solving word problems in various contexts with large numbers? And (3) did the intervention influence students' transfer of knowledge to performance on a norm-referenced standardized achievement test?

METHODOLOGY

Participants and Setting

This study was conducted within the larger context of the NSF-funded, *Nurturing Multiplicative Reasoning in Students with Learning Disabilities/Difficulties* project[1] (Xin, Tzur, & Si, 2008). Participants were three 3rd graders with school-identified LD, who enrolled in an urban elementary school in the United States. All three students (two boys and one girl) were included in the general education classrooms for 80% of the school day and they were all receiving Tier II and Tier III Response to Intervention

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(RtI) support. All the instruction and testing were conducted in the school's computer lab early in the morning Monday through Thursday.

Dependent Measures

The *criterion test* used in this study was a researcher-developed 10-item test that assesses multiplicative reasoning (MR-test). Other tests included in this study were: a 12-item word problem-solving test (COMPS-test, Xin et al., 2008) that contains a range of multiplication and division word problems involving large numbers; Stanford Achievement Test (SAT-10, Pearson Inc., 2004)a norm-referenced test involving a subtest on mathematics problem solving. SAT-10 was used as a far-transfer measure. In addition, during the tutoring instruction, probes were given to assess students' mastery of the skills pertinent to each of the four modules of the PGBM-COMPS program.

Procedure

An adapted multiple-probe-design (Horner & Baer, 1978) across participants was employed to evaluate potential functional relationship between the intervention and participants' word problem-solving performance.

All three participants completed one MR-test during the baseline condition. Then one student (Lily) took another two equivalent MR-tests. Following the baseline, the intervention on Module A was first introduced to Lily. Once the data for Lily showed an accelerating trend, the intervention on Module A was introduced to the second student David immediately after he took two additional baseline MR tests. The same sequence was followed until all three participants were introduced to Module A intervention. Following Module A instruction, a probe on the criterion MR-test was taken before Module B instruction took place. After Module B, another probe was taken before Module C & D was introduced. Posttests were given following all modules' instruction.

Participating students worked with the intelligent tutor one-on-one on a laptop computer four times a week, with each session lasting about 20-30 minutes. Sessions were supervised by trained Research Assistants (RAs). Their roles included administering pre-post assessment, fixing/recording computer/program's "bugs" and guiding students to appropriate part of the program after any unexpected "interrupt." Participants received about a total of 20-28 sessions during the spring semester.

Intervention Components

The PGBM-COMPS tutoring program is composed of four modules (A, B, C, & D). Module A focuses on multiplicative double counting (mDC). When working with mDC tasks, students learn the concept of *composite unit* (CU). For example, in the following question, PGBM 7 towers with 3 cubes in each, how many cubes in all?, students learn to consider 3 cubes as a CU and count 7 times of such unit for solution.

Module B involves tasks to develop skills in *unit differentiation and selection* (UDS) and multiplicative *mixed unit coordination* (MUC), which make sure students know on which unit they are operating, whether it is the # of cubes [the 1'] or # of towers [the CU]. Module C and Module D present quotative division and partitive division tasks respectively. In this part, students learn to solve the problems either through mDC or dividing cubes into equal-sized groups for solution.

Following PGBM components in Modules A, C, and D, the COMPS component engages students in representing word problems in mathematical model equations (e.g., unit rate x # of units = product, Xin, 2012) and then solve for the unknown (could be any of the two factors or the product) in the equation.

RESULTS AND ANALYSIS

The figure in the Appendix presents three students' performance on the MR and COMPS tests during baseline, intervention, and post-assessment. Each student's performance in the PGBM-COMPS tutoring program is described as follows:

Lily

In the baseline, she used addition and subtraction for solving all problems and got 0 points for all the tests. After the intervention was imposed, she demonstrated a steady increase on the MR- test (See Figure 1, the blue diamond data points and its data path across the phases) and learned to use multiplication and division but the increase was not significant. Her performance in the probes following each module was relatively low except for the last phase (module C and D instruction) where she had a steady increase in performance. Within all the modules, her performance in module B was poorest. However, she got great increase on the COMPS posttests-t. The transcript of her working video supports several explanations for her difficulties in learning of each module and poor performance in the MR- test and probes. First of all, she could not concentrate on the tasks very well. She kept clicking on everywhere of the screen, which often caused the computer frozen and the program restarted. This wasted a lot of learning time, which caused her not go through the whole study in each module because time allotted to each module was limited.

David

David demonstrated a steady increase on the MR criterion test throughout the program and also had great improvement in COMPs test. Within all the modules, module B was the most struggling part for David and he had difficulty in module B UDS part (See the transcription and Figure 1 below):

Module B UDS, David, 04/24/2013

The problem is "Tom has 4 towers of 5 cubes in each, John has 4 towers of 10 cubes in each".

Program(P):	How are these collections similar?
David(D):	Chose the choice of "They have the same number of towers"
P:	That's correct. How are these two collections different?

D: Chose the choice of “They have different number of towers”

P: That’s incorrect.

D: Chose the choice of “John has more cubes in each tower”

P: That’s correct. How many more cubes does John have?

D: Input "5"

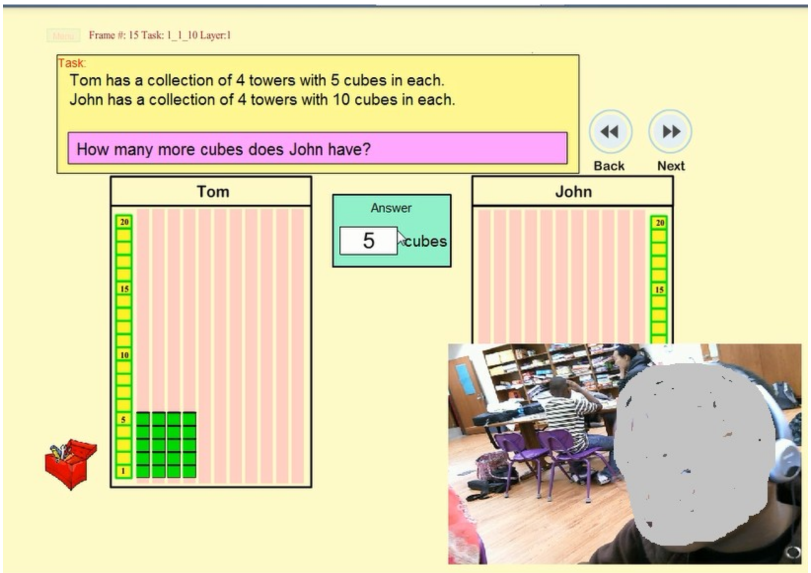


Figure 1

Neal

Similar to Lily and David, Neal also showed significant increase in COMPS-test, but he showed inconsistent and unsteady performance in MR-test. The probes scores indicated that module B was a struggling part for him. In addition, he had motivation problem. In the pretest and module A phase, his attitude was positive. However, from module B, where he faced strong struggle and had RA repeating prompting and instructing him, he became impatient and not concentrated on the tasks. In the post-test phase, he didn’t what to take any test and often showed miserable look on his face and RAs had to provide cookies as a reinforcement to have him finish the tests.

DISCUSSION

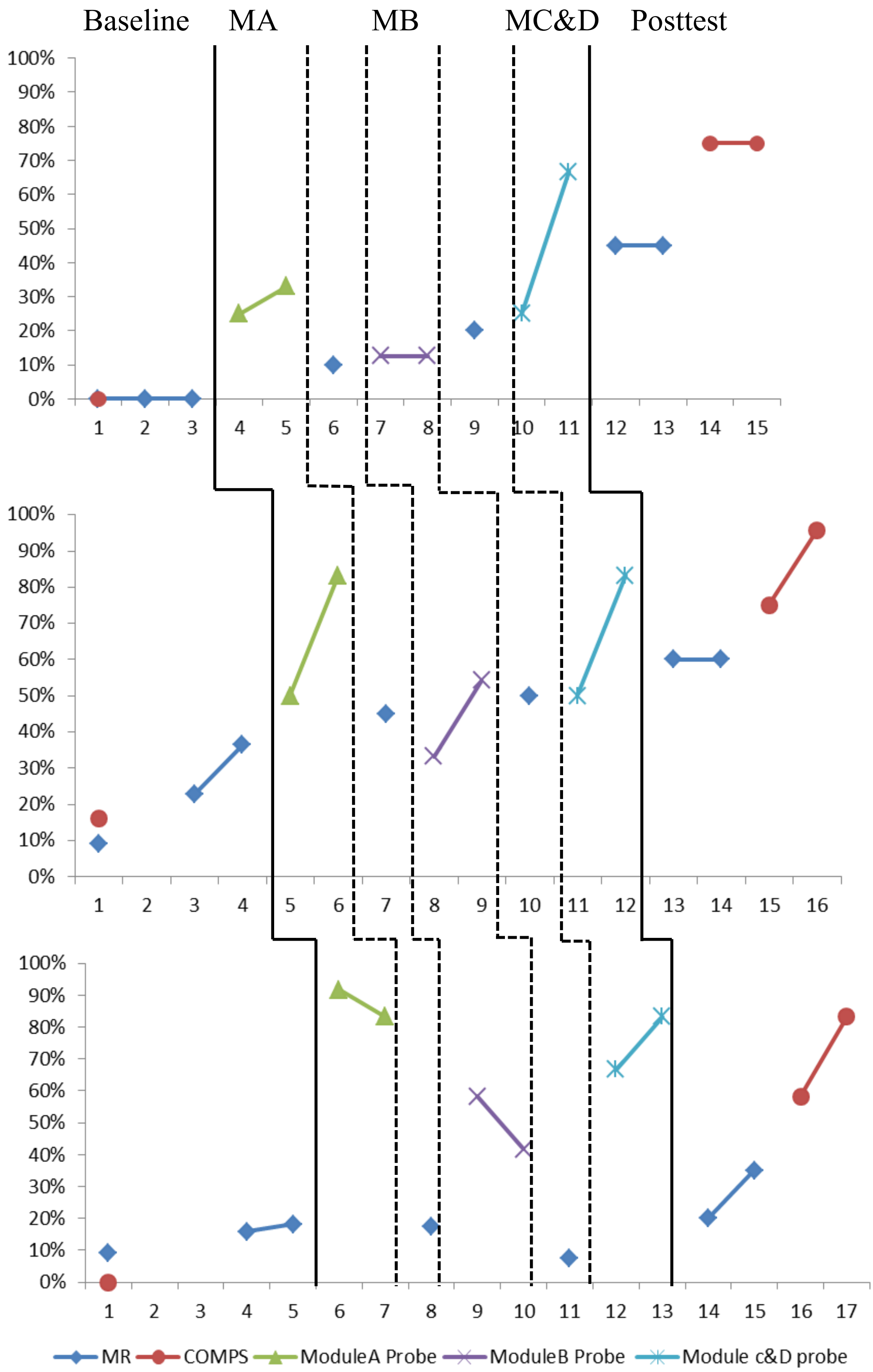
The PGBM-COMPS is probably the very first intelligent tutor that was created based on a research-based model of how students with LD develop multiplicative reasoning via reform-oriented pedagogy. Generally speaking, all three students’ performance in module B was relatively poor than their performance in Module A, C & D. One explanation for this might be that the UDS part in Module B involved two-step problems, which posed a challenge for these participants. Since module B is the second part of the program, at this point, the students did not have enough ability to solve such challenging tasks. Also, to solve two-step problems, the participants needed to hold and simultaneously process much information in their mind. Since students with LD had poor working memory (Richard, 2012), it posed challenge on the participants to solve the two-steps problems. It is documented that students with LD performed at significantly lower levels than students without disabilities on multistep problem solving (Xin, 2005). So in the future research, it would be better to move UDS part to later phase.

In addition, two out of the three students (Lily and David) demonstrated a steady increase on the criterion test (i.e., the MR-test) administered throughout the intervention but the increase was not significant. The third participant, Neal, showed inconsistent and unsteady performance. On the other hand, it seems that all three students significantly improved their performance in solving contextualized word problems on COMPS-test. There are several reasons for this result. First, COMPS component was taught at the last stage of the program and when the COMPs tests were administered, the students may still have fresh memory of COMPS knowledge, which caused them perform well in COMPs test. Second, along the dimension of MR, the current support build in the system might not be sufficient to address the disadvantages of students with LD, which might have contributed to the relatively lower performance on the MR-test. By comparison, the COMPs component involved some elements that might have better addressed the disadvantages of students with LD. For example, in the COMPs part, the important words of problems were highlighted and three key elements (Unit Rate, # of Unit and Product) were mapped to mathematical model equation, which contributed to better catching students' attention to the crucial parts. Further, the model equation drove the development of the solution plan.

However, in the MR component, there were many items on the screen without the important parts stressed. Students were easily distracted and got lost in information "overflow." Session observation data indicated that two of the students (Lily and Neal) had trouble to concentrate on the tasks.

Thirdly, MR-test was designed to assess students' multiplicative reasoning ability. There are several types of problems in the MR-test. For most of the one-step problem, participating students had more success. For example, in the pretest, the participants mainly used addition and subtraction for solution. But after the intervention was imposed, they knew to use multiplication and division for solution. However, participating students had more difficulties in solving two-step problems in the MR-test. If provided with more supporting strategies in solving two step problems, these students might have more access to the mathematics problems involved and their multiplicative reasoning might be better assessed. In addition to providing more scaffolding to these students, the future research might consider modifying the instructional sequences of the modules in the intelligent tutor.

Appendix



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