NON-LANGUAGE-BASED INSTRUCTION IN MATHEMATICS

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A substantial barrier to early learning of mathematics arises from undeveloped language understanding. Research conducted by the MIND Institute (www.mindinstitute.net) has investigated new methods of teaching that don't rely on language proficiency. The innovative methods developed out of this research have shown highly successful results in a population of over 20,000 kindergarten through 5th grade children in Los Angeles and surrounding areas. The methods make use of interactive computer environments to convey and develop mathematical knowledge visually, without the use of language. Basic procedural and computational skills are developed in parallel. The computer environment and teaching techniques will be demonstrated and discussed, and the quantitative and qualitative results of the program will be presented. Because of the language-independent nature of the teaching methods, the results have broad international implications for the improvement of mathematics instruction.

BACKGROUND AND DESCRIPTION

The traditional methods of teaching mathematics involve conveying concepts predominantly through the use of language. As a result, students that have trouble with language often have increased difficulty learning mathematics. “Trouble with language” can come in many forms. In one form, the symbolic and technical language of formal mathematics creates a stumbling block for students, even those that excel in the language arts. Very young students that are still acquiring their native language are another form. A form of language difficulty that is of particular interest in the USA is found in students whose native language is different from the language used for instruction in the classroom. In the USA, these students are referred to as English Language Learners (ELL), and they usually have a very hard time with mathematics (Gandara, 2000). For example, on high school exit examinations, ELL students typically perform worse on the mathematics portions of the exam than on the English Language portions (Jepson & de Alth, 2005). The MIND Institute has researched these different language barriers and has developed non-language-based methods of mathematical instruction (Peterson, 2000) that are able to reduce these barriers to learning and greatly increase the achievement in mathematics for a wide variety of student populations (Graziano, Peterson & Shaw, 1999; Martinez et al., 2005).

The unique aspects of our approach revolve around the innovative non-language-based methods of presenting and developing understanding of sophisticated mathematical concepts. Computer software is used to first convey mathematical ideas visually without words, symbols, numbers or other language-based representations. Children are motivated by the videogame-like aspects of the software to interact with the virtual models of mathematical principles. Scores are awarded for correctly manipulating the model to solve posed visual problems. The problems start off trivially easy, and gradually increase in sophistication as the child exhibits mastery of the fundamental concepts. The software probes the user’s understanding of the concepts, and uses level metaphors (adapted from video games) to advance the user through the content.

A key to the effectiveness of this non-language-based approach is the immediate and illustrative feedback provided by the software. When students make mistakes, the software illustrates the consequences of those mistakes visually to provide insight into why the action was incorrect. When children make correct actions, the software allows the students to visualize why the result worked. This feedback is provided in a way that is conducive to mathematical learning. After students gain proficiency at solving the visual mathematics problems, the software then teaches the students how to use language to describe what they have come to understand visually. The students learn both how to translate their visual understanding into mathematical language, and how to translate mathematical language into a visual representation.

This non-language-based approach is very successful in fostering a strong conceptual understanding of elementary school mathematics. However, it is evident that in addition to acquiring conceptual knowledge of mathematics, students must also become adept at related procedural and computational skills (Kilpatrick et al., 2001). Research has shown that the procedures and basic facts of arithmetic are more effectively learned and retained if the student first understands the conceptual meaning behind the procedures and facts (Brownell & Moser, 1949; Gray, 1965). For this reason, the software develops and provides extensive practice for procedural and computational skills after the student exhibits a conceptual understanding of the related topic.

So far, we have only discussed the computer software component of the educational method. It is important to make clear that there is also a classroom component guided by a teacher. A computer environment can only partially develop a child's mathematical knowledge and abilities. In our approach, the teacher still plays a vital role. In a typical elementary school implementation, students attend computer sessions for two 45-minute sessions per week in addition to three or more classroom math sessions per week. In our program, the role of the teacher includes but is not limited to the following:

1) Making connections between what the students learn from the computer-based lessons and other areas: Other areas include everyday situations, classroom learning activities and content presented in mathematics textbooks.
2) Fostering mathematical communication: Even though the students perform well on the computer-based activities, they don't readily know how to explain or express the mathematical concepts. The students need opportunities to try to communicate the mathematical ideas in their own words. It is also beneficial for students to hear how other students express and convey mathematical ideas. Only a teacher can provide such opportunities and supply the appropriate interactive support and feedback necessary to achieve these objectives.
3) Helping students develop strategies and mathematical reasoning abilities: Although the computer environments are designed to guide students in the building of strategies for solving mathematical problems, some students inevitably get stuck and need assistance that the software was not programmed to provide. Here the teacher is extremely valuable. The software provides a web-based reporting feature that allows the teacher to view student progress for an entire classroom. From this report, the teacher can see which students need additional attention and guidance. Since typically only a small portion of students need extra help at any point in time, the teacher can come around while the students are engaged in the computer lessons and provide invaluable one-on-one tutoring and guidance.

To summarize, our approach consists of a computer learning environment and classroom instruction. The software first introduces math concepts visually, without the use of language, using a computer-game context. In this way, the content is approachable by every student, regardless of language abilities. The software provides informative, animated feedback which illustrates mathematically why the student's actions are successful, or else why the student is making mistakes in solving the problems. After the student succeeds, demonstrating a visual understanding of the concept, additional computer exercises are provided which teach the student how to translate back and forth between the visual understanding and formal symbolic and language-based representations. After the student has exhibited an understanding of a concept, additional computer exercises are presented to develop related computational and procedural skills. In addition to the computerized lessons, classroom sessions further develop the ideas and skills, make important connections to broader contexts, and provide opportunities for the students to communicate mathematically.

METHODOLOGY

Over 20,000 kindergarten through 5th grade students in over 100 California and Texas elementary schools participated in a multi-year study of the effects on mathematics achievement of the non-language-based math program as described above. The computerized component of the program consists of over 400 lessons aligned to the math standards at each grade level as defined by the local state education authority. State-administered standardized test sores are used to measure mathematics achievement. In addition, individual student progress and performance data on the computerized lessons are tracked via the Internet. Data from the computerized lessons are correlated with standardized test scores and further analyzed using data mining techniques.

The multi-year study began in 1997, and is still in progress in 2006. The following provides a timeline of the methodology over these years:

Years 1997 − 2001

During this time, small to medium-sized controlled experiments were performed with up to hundreds of participating students at the 2nd and 3rd grade levels. The methodology and results of these experiments are detailed elsewhere (Graziano et al., 1999; Peterson et al., 2004; Martinez et al., 2005)

Years 2002 − 2003

During these years, over 6,000 2nd, 3rd and 4th grade students in 27 California elementary schools participated in a large-scale controlled experiment. The majority of the students were identified as being from economically disadvantaged households, with high percentages of English Language Learners. The treatment group consisted of 4,173 students from classrooms where the teacher volunteered to participate. The control group was composed of 1,546 non-participating students from the same grades and schools. All classes consisted of heterogeneous groupings of students related to mathematical abilities.

The treatment group students were provided the non-language-based computer lessons twice a week covering mathematical content appropriate for the grade level. The control group students were taught using regular, established methodologies. The amount of time and effort applied to math instruction in both groups was similar.

All students in the program were administered two tests of math competence, California Standards Test (CST) and the California Achievement Test, Form 6 (CAT6) in the spring of 2003. The results of these tests were to be used as a summary indication of performance for the use of the treatment program. The CST is a criterion-referenced test that produces an indication of mastery of math concepts appropriate for each grade level. Students are rated in five categories, based on performance (Advanced, Proficient, Basic, Below Basic, and Far Below Basic). The CAT6 is a standardized test of math concepts appropriate for each grade level. It produces a set of scores based on individual performance compared to national standards. The scoring chosen for this study was the National Percentile Rank (NPR), which indicates what percentage of students scored lower than the individual.

Years 2004 − Present

The methodology used in years 2003-2004 were extended to the present using CST results to measure achievement. When feasible, individual students were tracked from year to year to provide a longitudinal view of the program's effectiveness. In addition, data mining techniques were employed to analyze the large amounts of performance and progress data collected from computerized lessons. From the data mining analysis, trends in the learning of individual math concepts were analyzed. Details of the data mining methods are presented elsewhere (Hu et al., 2004).

CONCLUSIONS

Details of the data and results will be presented at the conference. In brief, the findings are extremely consistent over the experiments conducted from 1997 to the present. On average, treatment group students in the program exhibit a 15 to 20% improvement on standardized test scores versus control group students. The differences are highly statistically significant. The longitudinal results are even more impressive. Students in the program multiple years that we were able to track from 2nd grade are now in middle school. Compared to their peers at the same district, they are the top performing students in mathematics in every category. For most of these longitudinal students, English is not their primary language. As expected, we find that the increases in math achievement are independent of language proficiency.

Anecdotal evidence shows added benefits of this approach to learning beyond increases in math proficiency. Teachers consistently report that students are able to focus their attention for longer periods of time. Educators also independently report that because this program allows a higher percentage of students to succeed in learning sophisticated math concepts, these students gain confidence in their general ability to tackle difficult problems, regardless of the subject area. A third, but perhaps most important side benefit is that students universally enjoy learning math through this approach. As a result, more students are instilled with the love of mathematics.

The findings presented here demonstrate the effectiveness of non-language-based methods of teaching mathematics. Interactive computer environments, when properly constructed, are capable of developing both a deep conceptual understanding of mathematics as well as solid procedural and computational skills. Furthermore, by first presenting the concepts visually, without the use of symbols or language-based representations, these computer environments are approachable by students regardless of their linguistic background or language comprehensions abilities. Because of the language independence, these results have broad international implications for the improvement of mathematics instruction.

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