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A Study of Pre-Algebra Learning in the Context of a Computer Game-Making Course

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Introduction

In this paper, we report on the results of the first implementation of *GameMath!*, a new pre-algebra learning curriculum based on game development, or *game-making*. The curriculum is the result of a National Science Foundation Creative IT grant to explore novel ways to teach standards- based content and 21st century skills to underperforming high school students in Los Angeles. The project's goals are to address retention, career education and secondary mathematics learning. Game development is being used to engage students and to provide a grounding context for the mathematics. The effort is meeting the challenge of teaching math across the curriculum and is leading to the development of new strategies to embed mathematics in authentic contexts.

The original Pedagogical Games program was envisioned with four tracks: a game-making track, a game-design track, a mathematics track, and an online collaboration track to support team-based game design. With respect to mathematics, producing games exposes students naturally to logic, math and computational thinking. For example, concepts such as rates and fractions become accessible to students who must set player speeds to grid multiples to ensure safe passage through mazes. Data collected during play testing sessions can be averaged and graphed to analyze game design. Logic is introduced naturally. The challenge then becomes actualizing these concepts and assessing student learning of them[1]. The work presented here describes the first assessment outcomes for the mathematics track of the project.

Motivation and Framework

Teaching secondary mathematics as an isolated subject is not working for a large segment of the population, and may be holding back large numbers of students who might otherwise contribute Science, Technology, Engineering and Mathematics (STEM) talent to both work and defense forces. In Los Angeles, in particular, with its low graduation rates and low academic performance indices, motivation and achievement are two major concerns. With standardized mathematics tests often serving as a gatekeeper to further STEM learning, the inability to perform well discourages the learning of high levels of computational literacy and computer programming that are critically necessary for today's digital world.

Meanwhile, the intrinsic cultural attraction of digital game playing is undeniable, with video and computer game market revenues expected to reach over $100 billion in 2014[2]. While many educational games have been developed to teach preK-12 mathematics, there is also potential for learning mathematics through game development itself. Like robotics, game-making provides a foundation for engaging youth in learning critical STEM skills. Educators at all levels have begun to exploit the attraction to games to promote student engagement and creativity, and as a strategy to teach K-12 programming through platforms like Storytelling Alice[3,4,5] and Greenfoot[6,7]. Studies that focused on motivating female students to learn information technology showed that game design engaged students in activities that promote critical thinking, problem solving and decision-making[8].

Learning in the context of computer game-making is best framed by the philosophy of Constructionism, which is *the idea that learning is most effective when part of an activity the learner experiences as constructing a meaningful product*[9,10]. Following a recent trend in STEM education, the program uses a *STEM* to *STEAM* approach to learning, which is the practice of integrating art and/or design with traditional STEM learning to increase interest and impact[11]. The importance of the practice is being recognized at high levels[12].

Methodology

During the fall of 2011, fifty students participated in a games course to study mathematics learning in the context of making computer games. The school's Film instructor taught the course, assisted by a team of four masters level students at the University of Southern California. Due to demand, two periods of the course were taught. During the class students created two different games – a *Maze* game (e.g. PacMan) and a *Shooting Scroller* game (e.g. Space Invaders). Each game exercised a different set of mathematical concepts. Students spent about eight weeks on the Maze game and about six weeks on the Shooter game. Game-making classes were interspersed with activities that involved mathematics directly and indirectly, for example math worksheets and games with embedded math quizzes, and manipulation of concepts that occurred while making games, such as aspect ratios and animation rates. Students took short self-quizzes after each game tutorial (about eight per game) to reinforce game and math concepts. The quizzes focused on both games and math concepts. A pretest and posttest were administered before and after students created each of the two types of games.

The study was performed with high school freshmen in East Los Angeles. The Academic Performance Index (API) of the school was 615/1000 in 2010 and it had significant populations in the following key areas: "Hispanic/Latino", "Asian", "Socioeconomically Disadvantaged", and "English Learners" [13]. In summary, the target population was a significantly underperforming population of students who are underrepresented in STEM majors and careers.

In this paper, our analysis focuses on pre- and post math tests that were administered before and after students created each particular genre of game. Each test (Maze and Shooter) consisted of the same ten questions. The tests were designed to measure mathematics learning related to the intervention, i.e., making the game, however, school administrators had asked if we could relate the game math problems to California High School Exit Exam (CAHSEE) problems, so we added two related problems from published CAHSEE exams to each test. The Maze tests were paper-based and the Shooter tests were administered electronically through Moodle. For the Moodle based tests, the display of both questions and answers were randomized to prevent copying.

The decision to emphasize the games' pre-algebra mathematics concepts was based on diagnostic results of a suite of pre-algebra readiness problems developed by the Mathematics Diagnostic Testing Project[14], on which none of the 9th grade students passed the proficiency threshold, and also on conversations with administrators, in particular their concerns that every child be able to pass the CAHSEE as soon as possible. This decision dovetailed with our original goal to focus on math concepts that were organic to the games students would design, as opposed to creating a game curriculum for a pre-determined set of math concepts. While the latter is possible, the project goal was to impart mathematics within an authentic context; if particular math standards were omitted, that was fine.

Results

In this section we present the results of the pretest and posttest, and item analysis for the Maze and Shooter games. For the Maze game test, 45 students took the pretest and 49 took the posttest. For the Shooter game test, 20 students took the pretest and 13 took the posttest.

Pretest and Posttest Differences

Data from pretests and posttests were analyzed and are shown in Table 1. For the Maze game comparison, after unmatched samples were removed, the final sample size was 31 pairs. For the Shooter game, the final sample size was 12 pairs. We removed a pair of scores that went from 7.9 on the pretest to 1.0 on the posttest, which we agreed was done deliberately.

Table 1: Mean score comparisons for Maze and Shooter tests.

Game (Sample Size) (Max Score)	Mean Score		Percent Correct		T-Test	
	Pretest (std)	Posttest (std)	Pretest	Posttest	Value	Significance (2-tailed)
Maze (N=31) (Max=9)	1.6 (1.4)	3.2 (2.6)	28.3%	49.5%	3.76	0.001*
Shooter (N=12) (Max=8)	5.8 (2.7)	6.2 (1.5)	72.5%	77.5%	0.54	0.434

We looked at mean score, correctness percentage, and paired sample t-tests. Both sets of posttest scores were normally distributed. There was a significant increase in means between the Maze pretest and posttest results. While making the Maze game, students completed five math worksheets (about 30 minutes each) and eight self-quizzes. There was a positive non-significant increase in the mean for the Shooter test. While making the Shooter game, students completed three math worksheets and nine self-quizzes. On this pretest, 25% of students scored below a 4 (out of 8), while all students scored at least 4 on the posttest. However six students scored an 8 on the pretest, whereas no one did that on the posttest. This is almost certainly due to the fact that some students retook the pretest multiple times in Moodle, an inadvertent consequence of administering the tests electronically for the first time (similar to the paper version, students should have been able to take the test only once). We changed the settings for the posttest. It is likely that the higher scores on the pretest could have flattened out the learning gains for the Shooter study.

Pretest and Posttest Item Analysis

A more detailed item analysis was done on the individual questions, to help us understand, as part of the iterative design of the game math track, which concepts were most difficult for students, and which worksheets/tutorials were succeeding in teaching particular concepts. Results are shown in Tables 2 and 3.

Table 2: Item analysis for the Maze game test.

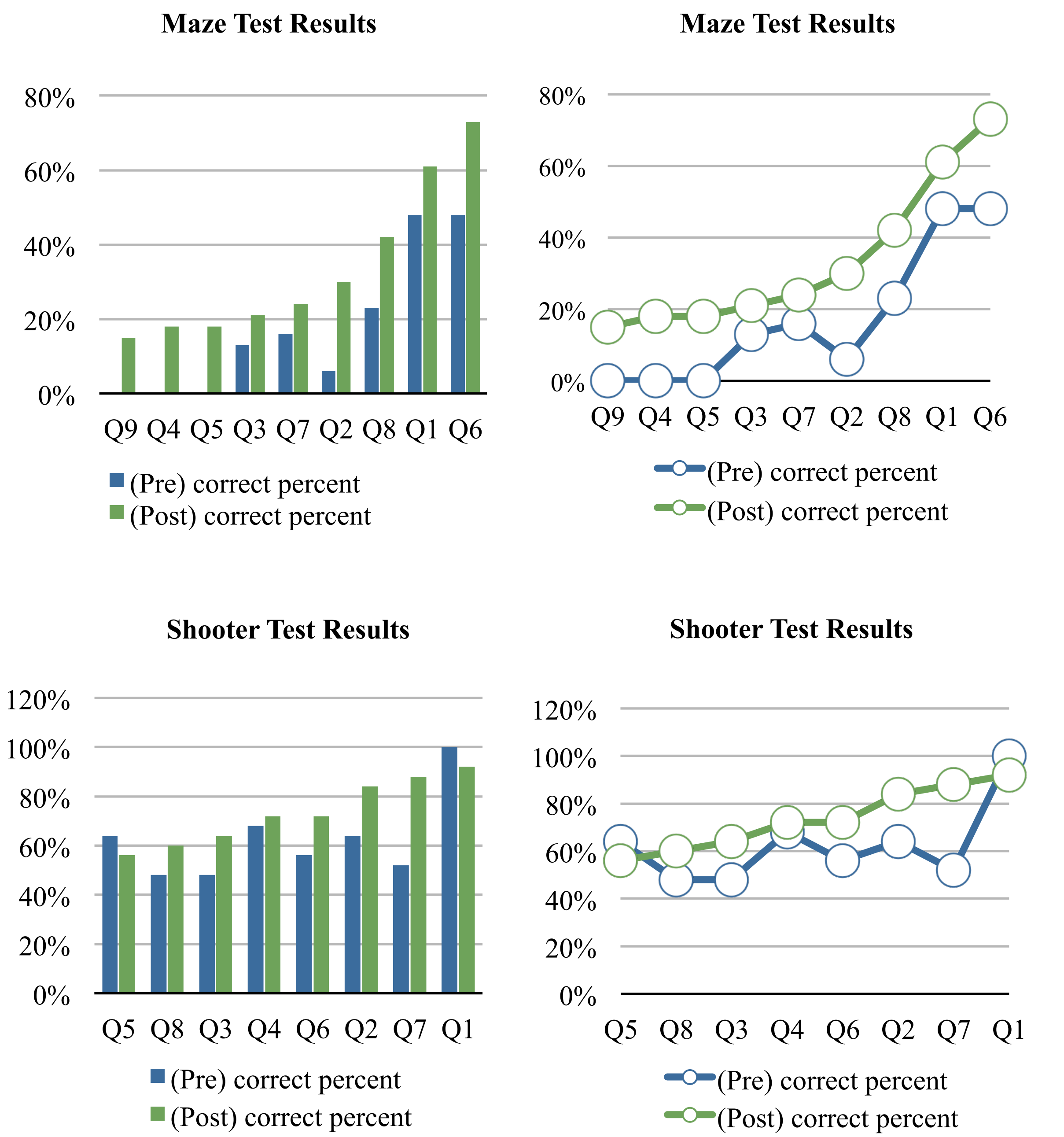
Maze Game Question Number and Concept		Pretest Students Answering Correctly Num (Pct)	Posttest Students Answering Correctly Num (Pct)	Percent Change (+)
Q9	Median calculation	0 (0%)	5 (15%)	15%
Q4	Area & fraction calculations	0 (0%)	6 (18%)	18%
Q5	Area & percentage calculations	0 (0%)	6 (18%)	18%
Q3	Least Common Multiple calculation	4 (13%)	7 (21%)	8%
Q7	Slope calculation	5 (16%)	8 (24%)	8%
Q2	Concept of "increase by 200%"	2 (6%)	10 (30%)	24%
Q8	Greatest Common Factor calculation	7 (23%)	14 (42%)	19%
Q1	Time calculation with speed, distance	15 (48%)	20 (61%)	13%
Q6	Draw graph given coordinates	15 (48%)	24 (73%)	25%

Table 3: Item analysis for the Shooter game test.

Shooter Game Question Number and Concept		Pretest Students Answering Correctly Num (Pct)	Posttest Students Answering Correctly Num (Pct)	Percent Change (+)
Q5	Probability calculation	16 (64%)	16 (56%)	-8%
Q8	Square number estimation	12 (48%)	12 (60%)	12%
Q3	Percent calculation	12 (48%)	16 (64%)	16%
Q4	Product calculation	17 (68%)	7 (72%)	4%
Q6	Probability calculation	14 (56%)	14 (72%)	16%
Q2	Average calculation	16 (64%)	21 (84%)	20%
Q7	Edge length calculation given area	13 (52%)	13 (88%)	36%
Q1	Get meaning from graph	25 (100%)	23 (92%)	(-) 8%

The highest learning gains for the Maze game occurred in graphing and rates concepts, as well as fractions, percentages and factors. The highest gains for the Shooter game occurred in the average, length, percent and probability calculations. Some of these concepts are directly related to a Shooter math game that was created for students. The type of probability calculation in Q5 was ultimately not covered. In summary, students improved on almost every question (Figure 1).

Figure 1. Maze test (top) and Shooter test (bottom) results.



Scholarly Significance and Conclusion

While teaching and learning mathematics within authentic contexts is appealing and full of potential, contextual learning, with its interactive and collaborative activities, can be difficult to assess. Although the results of the *GameMath!* study were positive, there was no control group to determine to what degree the learning gains occurred due to the game-making intervention and to what degree the gains were the result of learning in ongoing math classes. However, because disparate math concepts such as fractions, rates, and graphing were applied during a relatively brief time periods, e.g., eight weeks for the Maze game and six weeks for the Shooter, the likelihood that all of these concepts were taught in tandem in the students' corresponding math classes is low.

Several adjustments were made during the year the program was piloted, including implementing the tests electronically and adding math exercises for a third game (a platform game). In 2012, the program was piloted at a second school site, as part of a media arts class, and did not incorporate the math exercises. As interest in teaching the program as a media arts course increased, we were faced with how to "teach" mathematics in the absence of a credentialed math teacher. To this end, we have begun to rely less on standards-based math practice and more on assessing computational thinking and mathematical reasoning skills that are reflected in the game-making activities.

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