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## **AC 2012-4334: GAMEMATH! EMBEDDING SECONDARY MATHEMATICS INTO A GAME-MAKING CURRICULUM**

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# GameMath! Embedding Secondary Mathematics into a Game Making Curriculum

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## Abstract

This paper reports on our experiences designing GameMath!, a mathematics learning track for a new game making curriculum called *Pedagogical Games*. The curriculum is the result of an National Science Foundation grant to explore novel ways to teach standards-based content and 21<sup>st</sup> century skill to underperforming high school students in Los Angeles. The project's goals are to address retention, career education and secondary mathematics learning. Game-making is being used to engage students and to provide a grounding context for the mathematics. The effort has exposed the challenge of teaching math across the curriculum and led to the development of new strategies to embed mathematics in authentic contexts. The curriculum is being developed and implemented for the first time during the 2011-12 school year. Fifty ninth-grade underrepresented minority students from east LA are participating.

## Motivation

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. The potential for teaching pre-algebra and algebra as part of a game-programming course is great. The intrinsic cultural attraction of digital game playing is undeniable. Sales of video and computer games topped \$21 billion in 2008<sup>1</sup>. Educators at all levels have begun to exploit children's attraction to games -- with their constant reward structures that foster a sense of ownership and empowerment-- to promote student engagement and increase creativity<sup>2,3</sup>. However, until recently, especially at the K12 level, the focus has been on learners as consumers not learners as producers.

Like Robotics, Game-making provides a foundation for engaging youth in learning critical STEM skills. Mathematics is often a gatekeeper course for further STEM learning, and programming and computational literacy are necessary in today's digital world. Game-making, as evidenced by first person shooter games and networked social games, can provide a context for learning a wide-variety of skills and subject areas through development and simulation. Game-making is a strategy used to teach K-12 programming; and such platforms include Storytelling Alice (e.g. Moskal & Skokan, 2007; Bean & Denner, 2009, Werner & Denner, 2009) and Greenfoot (e.g. Leutenegger et al., 2007; Al-Bow et al., 2009). Studies that focused on motivating female students to learn information technology showed that creating games engaged students in activities that promote critical thinking, problem solving and decision-making (Denner et al., 2009).

The original project 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. 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 is averaged and graphed to analyze game design. Logic is introduced naturally. The challenge then becomes actualizing these concepts and assessing student learning of them. The work presented here describes our attempt to meet this challenge.

## **Target Population**

The target population comprises high school freshmen at a new Pilot high school in east Los Angeles. While statistics on the new school are not yet available, the population mirrors that of the large high school on whose campus it resides, having significant populations in the following key areas: “Hispanic/Latino”, “Asian”, “Socioeconomically Disadvantaged”, and “English Learners”. The Academic Performance Index (API) was 588/1000 in 2009 and 615/1000 in 2010. As a comparison, similar schools had a median API of 650 and 673 respectively. In summary, the target population is/was a significantly underperforming population.

Twenty five students participated in two six-week pilot studies during the spring of 2011. The first study focused on individual game-making and integrated mathematics and the second on collaborative game making and design tools. The game-making instructor and mathematics instructor, who taught during the math classes during the pilot study, were both credentialed to teach mathematics. This year there are two game-making classes and the mathematics is taught by the same instructor. Fifty students are now participating in a full scale implementation.

## **Methodology**

The GameMath! Pilot ran four weeks. The full implementation began September 2011 and is in progress. During the implementation, game making classes were interspersed with activities that involved mathematics either directly, e.g., working on traditional math worksheets or playing math games, or indirectly, e.g., creating games or participating in discussion activities.

Students were given surveys to evaluate their a) interest in games, b) technological literacy, and c) math motivation and college plans. A pre-algebra readiness test was given from the suite of standardized tests developed by the Mathematics Diagnostic Testing Project (MDTP, 2010). Decisions about math integration were based on the results, and also on conversations with administrators, in particular their concerns that every child be able to pass the California State High School Exit Exam (CAHSEE) as soon as possible. Moreover, a decision was made early on to focus on the mathematics that was organic to the games students would be designing, as opposed to designing a game curriculum for a pre-determined set of math concepts. While the latter is possible, the project goal was to work with authentic mathematics, so it could always be related to course work. If certain math standards were omitted, that was OK.

## Interest in games

All students play games, however, there is a clear difference between the games that interest boys (more violent) and the games that interest girls (music and arcade games). See figure 1a. Student responses to the games survey were compiled and used as examples of game genres to personalize a game design lecture. The results were also used to tailor examples of the “Shooting Scroller” game that students made; traditionally a plane fighting game, we prepared non-violent examples so the game wouldn’t be dismissed by the girls, for example, “capturing eggs to put in a basket”. As a result, one all-girl team designed a game where “Cupid shoots arrows to capture a heart”. Responses also showed that the majority of students played console games, which allowed us to emphasize career pathways (figure 1b).

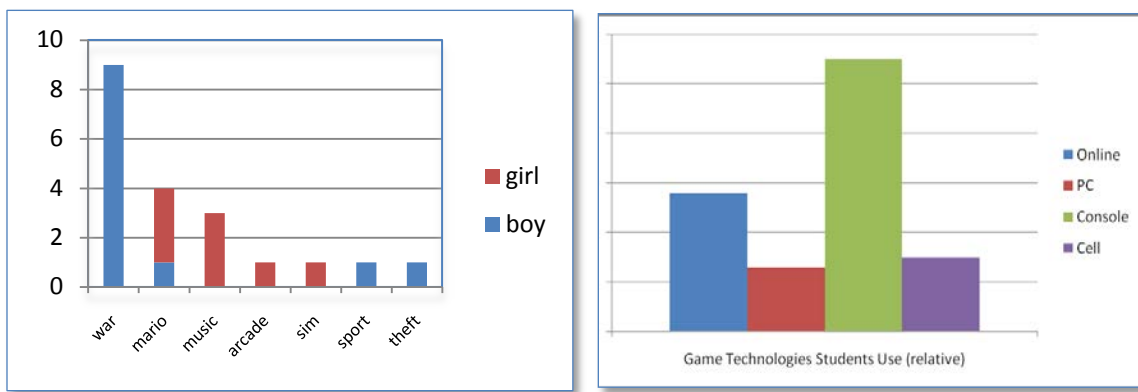


Figure 1a,b. Types of games played by students and games technologies used by students.

## Technological Literacy

The student sample is a low socio-economic and high free and reduced lunch population so there was a question about their access to technology, especially if homework was required (it wasn’t). Responses showed that 95% of students have at least one computer at home and over 90% have at least one game console (figure 2a). Moreover, almost 90% have an MP3 player or iPod, and 84% have a mobile phone. At least 90% of students reported playing games at least one hour a week, although this was low compared to time reported texting or talking by phone (figure 2b).

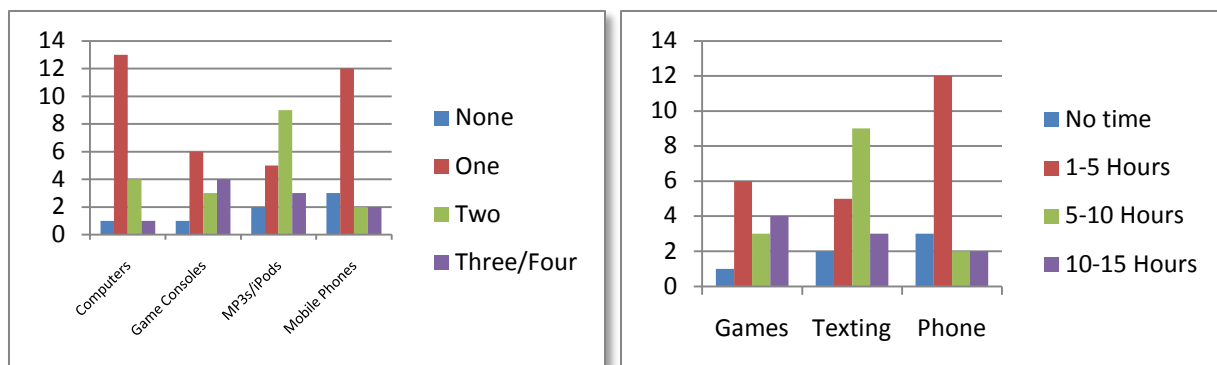


Figure 2a,b. Types of devices owned by students and number of hours spent comparison.

## Math Learning Profile

A questionnaire was administered to assess self-reported interest, ability in mathematics, college plans and entity beliefs. The results show that most students expect to enter college after high school (figure 3a). When taken together, the responses for *How much do you like math?* and *Compared to your other classes, how hard do you need to work in math class?* show that almost 70% of students don't like it or find it challenging (figure 3b), despite the fact that when taken together, the responses to *Is it important for you to do well in math?* and *After you leave school will you use math in your job?*, almost 80% of students think that math is important and will be used at work (figure 3c). Percentages are based on responses greater than three, on a scale of 1-5. However, as results of a standardized algebra readiness test showed (MDTP, 2012), none of these students met even one math topic threshold for algebra readiness in 9<sup>th</sup> grade. In summary, these students were aware of both the difficulty and importance of math, but were too disengaged to apply themselves to learn it. Moreover, the underperforming students were tracked together so that peer influence was an obstacle in overcoming academically self-destructive behavior, such as talking and texting in class. Traditional lecture style classes were failing because of frequent interruptions and the distraction of mobile electronics. We hypothesized that these students would require engaging project-based work if they were going to remain in school and graduate.

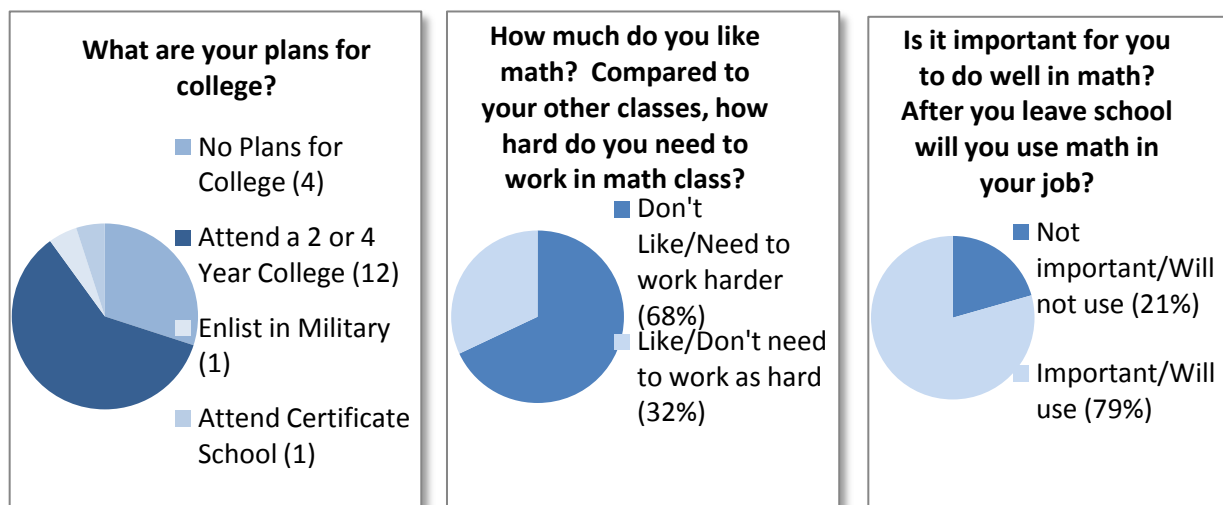


Figure 3a,b,c. Responses to questions about college plans, interest in/challenge of math and perceived importance/usefulness of math.

The students were then asked how well they thought they would do in math class and in the game development class. The majority of students perceived that they would do poorly in their math classes, but would do well in their game development class (figures 4a,b). In the next iteration of the instrument, we will ask if students think they will do better in math if the type of math they learn is useful for building games. These results led to an effort to try to relate the taught math to real life contexts in other ways, as described in the following section.

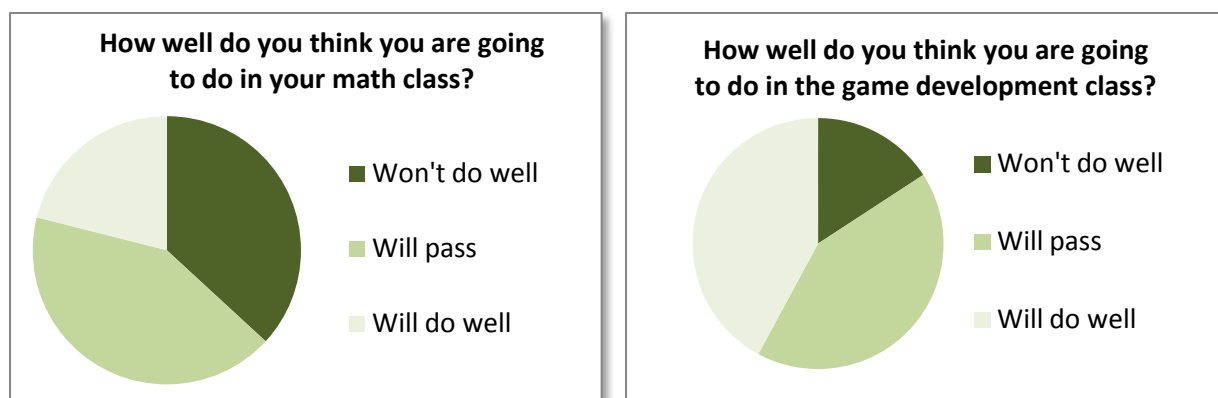


Figure 4a,b. Perceived outcomes in math and games classes.

### ***Math Skills Testing***

A math skills pre-test of eight questions was administered to assess student skill levels with respect to game math. It took two periods to administer because students simply would not take the test. We found this assessment-defiance behavior to be a pervasive problem with the target population, generally, and this strongly argues for the need to ground mathematics assessment in skills-based contexts, such as game-making. We made the problems easier the second time, and gave incentives for answering questions. There was some improvement but test validity was still a question. The same pre test was administered to two higher level algebra courses to control for ongoing algebra instruction. Although the pilot students were lowest tracked, their scores were not significantly lower than the others. After approximately ten hours of game and math instruction a post test was administered. There were again problems collecting the data, i.e. students refusing to take the test or writing “IDK” (“I don’t know”) after each problem. In conclusion, no significant learning gains were shown, but what the project team learned was that we would need to create different forms of assessment for the scaled version of the program.

### **Strategies for embedding math**

A typical first reaction of students, upon hearing that they will be learning math as part of their game course is surprise and objection. ‘This is a game making class, not a math class’ is the general sentiment. The objection is manifested at the time of the first pre-test, when students simply refuse to answer the test questions. In this section we present the different strategies and techniques we used to embed math content into the game making curriculum. The challenges were myriad and included introducing math into the curriculum, designing authentic integration, dealing with computer distraction, and translating games skills to standards-based content and ultimately their application in a standards-based text context. Students in the class create three games, a maze game, a shooting scroller game, and a platform game. In table 1, the types of games, associated math, and indirect and directly linked math learning activities are shown. The following learning strategies were tested during the pilot and/or the fall implementations.

- Mathematics organic to game-making.
- Introducing math as integral to game-making.
- Linking taught math to authentic contexts.
- Integrating math assessment and game-playing.

Table 1. Game, mathematics and activities to link them.

Game Type	Math Standards	Indirect Activities	Direct Activities
Maze	Number System, Coordinate Geometry, Rates, Ratios & Proportional Relationships	<ul style="list-style-type: none"> <li>Thinking about math as part of a games discussion.</li> </ul>	<ul style="list-style-type: none"> <li>Creating games (GM interface).</li> </ul>
Shooter	Number System, Coordinate Geometry, Geometry, Complex Rates, Statistics and Probability	<ul style="list-style-type: none"> <li>Reading about math using quotes from game-makers.</li> </ul>	<ul style="list-style-type: none"> <li>Collecting usability data.</li> </ul>
Platform	Expressions & Equations, Statistics and Probability, Creating Equations, Reasoning with Equations & Inequalities	<ul style="list-style-type: none"> <li>Working through math worksheets</li> <li>Working with usability data.</li> </ul>	<ul style="list-style-type: none"> <li>Playing pre-made games.</li> <li>Linking games to worksheets.</li> <li>Fixing pre-made games.</li> </ul>

### *Mathematics organic to game-making*

Students used Game Maker's (YoYo Games, 2012) game design platform to create games (figure 5). Math is used frequently during the game creation phase, for example, for the maze and shooter games include the following actions and, by definition, math standards.

- Player speed (MCS NS 1.2, NS 1.6)
- Player speed and pixels (MCS AF 2.1, MG 2.4, NS 1.2)
- Player and enemy speed (MCS MG 1.2, MG 2.4, NS 1.6)
- Shortest paths and timers (MG 1.2, MG 2.4, MG 3.3, NS 1.6)
- Play grid (MCS NS 1.3, NS 2.2)
- Graph analysis (MCS 2.3, GR7 SDAP 1.1)
- Play testing (MCS GR6 SDAP 1.1)

Examples of math use can be seen in the interface and include (figure 6, clockwise, from top-right), setting timer speeds, setting variables, setting room and grid sizes (and animation rates), creating conditional statements of step sequences, setting player speeds. Rates appear in several contexts, for example, when students set player movement speeds, window scrolling rates and animation speeds. Variables are used to store values for display. Step sizes have to be a multiple of the grid size, which in turn must be a factor of the room size. Students initially create games by rote, not really noticing the math they are using, so the tutorials are set up to introduce conflicts that cause problems that must be overcome, such as setting pixels per step to a number that is not a multiple of the grid size so that objects do not line up with the grid and cannot get through small maze openings. Formalizing problem solving within the domain is challenging because students are more interested in creating the game than learning about the math, and initially, it is more important to foster engagement. It is difficult to assess situated learning, e.g. math learned while game making, however we are currently developing techniques for doing so.

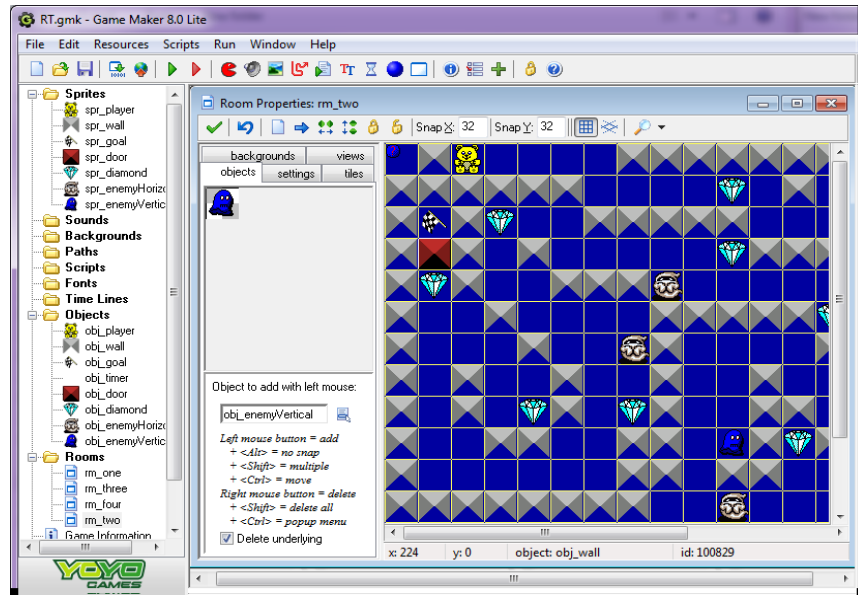


Figure 5. Game Maker design interface.

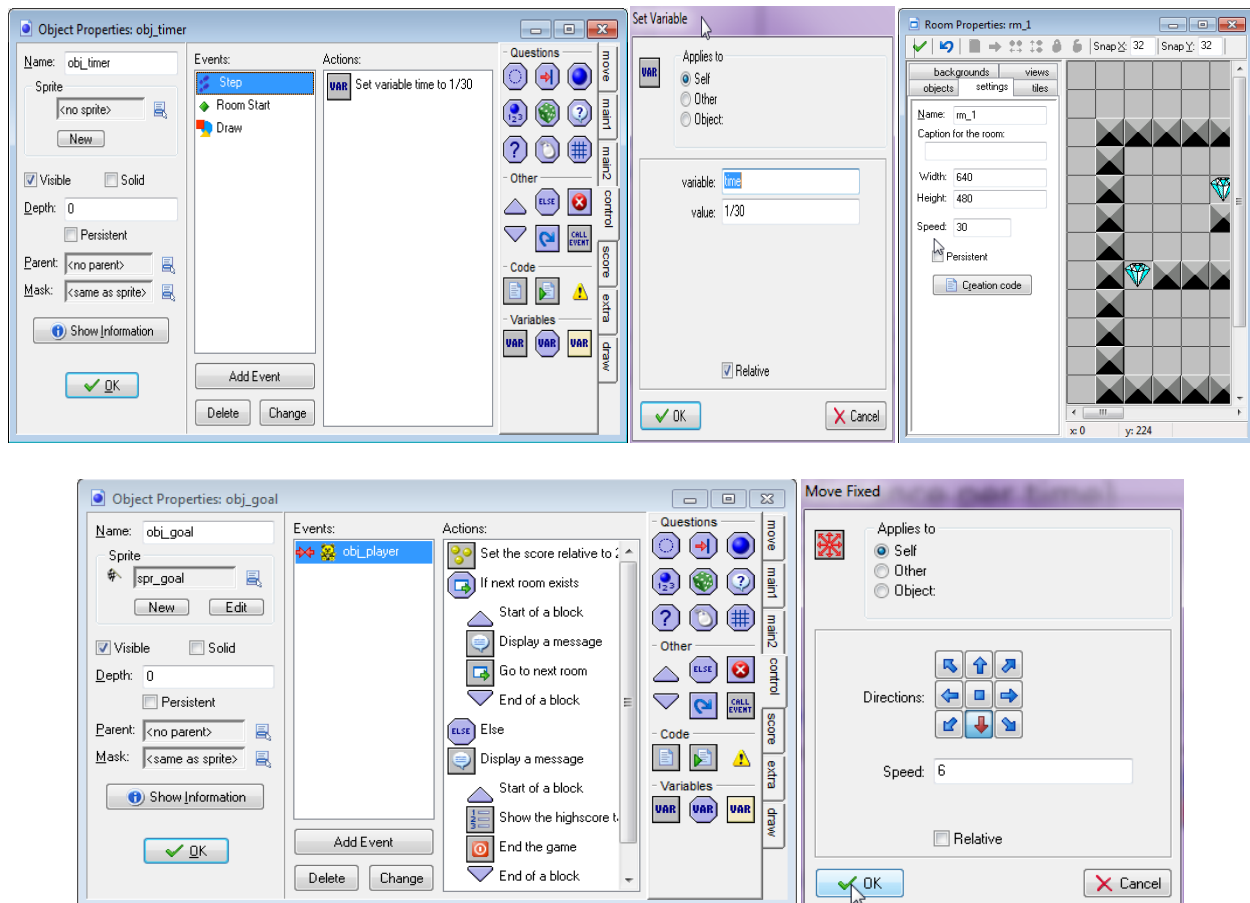



Figure 6. Using math within the interface.



## Introducing math as integral to game making

The program includes online activities to complement the team-based collaborative game design component. It became clear during the pilot study that students would need scaffolding activities for each of the different technologies they would eventually use, so that a few of these activities were added to the game and math component. This became an opportunity to introduce the role of math in game making. Other questions addressed other goals such as highlighting game-making careers, and tips for team collaboration. The entire class participated in the discussion activity. The question and some responses are shown in figure 7. An undergraduate computer science games major participated by commenting on responses. Although many students left off-task comments, all students were engaged in the activity and avidly read the posts.


**Game Math!**  
by Yezhisai Murugesan - Wednesday, 14 September 2011, 12:32 AM


**Mathematics is key to the art and technology used to create games.**

How do you think math is used in the games below? Answer the questions below, then respond to someone else's post.

**1. Angry Birds**

A popular iPhone game that uses math concepts like velocity, angles etc.  
How do different trajectories affect the results?

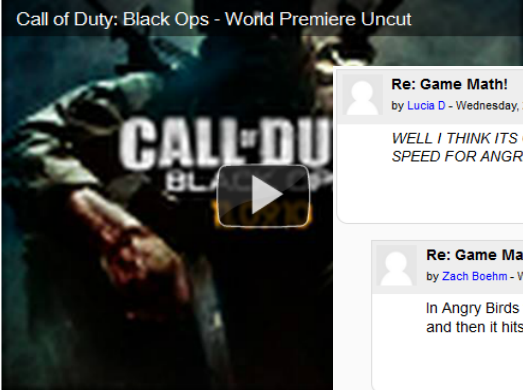



**Re: Game Math!**  
by Zach Boehm - Wednesday, 28 September 2011, 02:30 PM  
For God of War you have to calculate how far Kratos can jump and that affects how you design every ledge to jump off of.

Show parent | Edit | Split | Delete | Reply


**2. Call of Duty**

What sort of math is used in MMORPG's?  
What is the importance of numbers. (For example, How much mana?, What's your defense rating?, etc.)



**Re: Game Math!**  
by Lucia D - Wednesday, 28 September 2011, 02:49 PM  
WELL I THINK ITS OK BUT I MEAN ITS LIKE WHAT EVERS THE THING IS TO CALCULATE THE TIME AND SPEED FOR ANGREY BIRDS AND AIMING ..... :) THATS WHAT I THINK I DONT KNOW ABOUT OTHERS

Show parent | Edit | Split | Delete | Reply

**Re: Game Math!**  
by Zach Boehm - Wednesday, 28 September 2011, 02:52 PM  
In Angry Birds there are a lot of physics. When a bird hits a block, the game has to calculate if it will fall and then it hits a whole bunch of other blocks and has to figure out if they fall too.

Show parent | Edit | Split | Delete | Reply

Figure 7. Online discussion about math for games.

## Linking taught math to authentic contexts

For example, on a math worksheet that featured usability data collection and analysis, we began with a quote from game design article such as:

*“Every moment in a game, you’re bleeding players,” says John Hopson, Bungie’s user research lead. “Hopefully, you’re bleeding them as slowly as possible. The most powerful thing I ever did on Halo was making a graph showing how many players we lost each mission. (From <http://www.next-gen.biz/features/the-science-of-usability-testing>).*

When the worksheet with the quote was projected on the board, the students gradually discovered the text and the talking gradually subsided. This was in marked contrast to the usual response to a math activity. We plan to ask students if these quotes affect their classroom performance the next time the activity takes place.

Usability testing, data collection and data assessment directly links math and game-making. Play testing and analysis sheets are shown in figure 8. Data collection was actually a difficult task for students and took several classes to accomplish. A table-based round-robin approach was tried initially, based on the experiences of the team’s undergraduate games students. What worked ultimately, was simply asking students to go find someone who would test their games and provide data. Teachers and team members were there to test games as well, and contrasting student and adult results provided a compelling example of why medians should be used instead of mean averages to analyse game satisfaction (the adult data were all outliers.)

### GameMath: Play Testing

NAME: \_\_\_\_\_

Tags:  
MCS:

#### Instructions

Leave this sheet next to your game and switch places with someone from your class. Play their game. Fill in the time it takes to finish the first three levels of the game. (You must have a timer in your game!) Also record the number of times you failed before making it through the maze.

PlayTester Name	#Fail: Enter number of failed attempts before you finish a level. Time: Enter time from game timer after you finish a level.					
	Level 1		Level 2		Level 3	
	#Fail	Time	#Fail	Time	#Fail	Time

Give feedback about the level you are testing. Which one was your favorite (least favorite)? Which level did you find easiest (most challenging)? Fill in the level number below.

PlayTester Name	Level: Enter the level # (1, 2 or 3) for each question.			
	Most Favorite?	Least Favorite?	Easiest?	Most Challenging?

Developed at the University of Southern California and LEMA High School, LAUSD, 2011. Development sponsored by the U.S. National Science Foundation, Creative IT #1002901.

### GameMath: Analysis

NAME: \_\_\_\_\_

Tags:  
MCS:

#### Definitions

Usability testing consists of both user testing and play testing\*

**User testing:** To study if users understand how to use something correctly. The ‘something’ can be anything: a toaster, a mobile phone, or a video game.

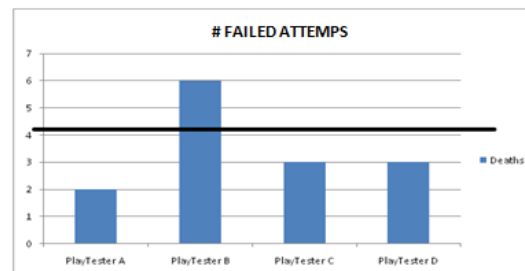
**Play testing:** To study if users enjoy playing a game.

“Every moment in a game, you’re bleeding players,” says John Hopson, Bungie’s user research lead. “Hopefully, you’re bleeding them as slowly as possible. The most powerful thing I ever did on Halo was make a graph showing how many players we lost each mission.

\*From <http://www.next-gen.biz/features/the-science-of-usability-testing>

#### Example

Luis asked four play-testers to play his game and to record how many times their playable character failed on level 1. He graphed this data on a bar graph. He then drew a horizontal line to estimate the average number of deaths.



Question 1.1: Estimate the average number of deaths from the graph.

The line was placed between the tallest bar and the lowest bars. Because the line crosses the y-axis at about 4.2, Luis’ estimated average was 4.2.

Developed at the University of Southern California and LEMA High School, LAUSD, 2011. Development sponsored by the U.S. National Science Foundation, Creative IT #1002901.

Figure 8. Usability data collection sheet and associated worksheet where results are applied.

### *Integrating math assessment and game playing*

Two different strategies were tested. In the first, math worksheets were linked to playing pre-made games that were versions of the games students were making. Playing the games helped students answer problems in the worksheet; i.e., students needed to play the games to solve the scenarios in the worksheets. In the second, students used games that were developed by the team's undergraduate and graduate games programmers (similar maze and shooter games).

Consider the maze game under the question in figure 9a. The goal of the player is to reach the flag. Interactive problems from the above problem can be formulated as follows:

- Count the number of empty tiles between the player and the flag.
- If each tile is 32 pixels wide and 32 pixels high, calculate the distance the player has to travel to reach the goal.
- If speed of the player is 16 pixels / step, how many steps the player will have to take to reach the goal.

Questions about perimeter, area, and fractions are natural in this setting. In this example, the student has to count how many tiles wide the maze is by converting the number of tiles to number of pixels. The student is then given the total number of pixels the screen is wide and asked to calculate what percent of the screen's width the designed maze takes up. If the student answers questions wrong, a hint is given and the student retries the problem. Correct answers allow the student to play the game. This was tried in front of the class and students who answered correctly were permitted to go up, play the game and drive the next question presented to their classmates. The motivation level was high. In another example, shown in figure 9b, students have to figure out the initial velocity that needs to be set for the dog to cross the hurdles. There is also the concept of gravity concept in the game, which students can tweak to allow the dog to complete his challenge.

The strength of these tools is that the students can open these Game Maker files and change the configurations. Game scripts can also be inserted into games the students design and run, and the questions become questions about the students' own games. This experiment will be tested in the future, but the games were designed for this reason.

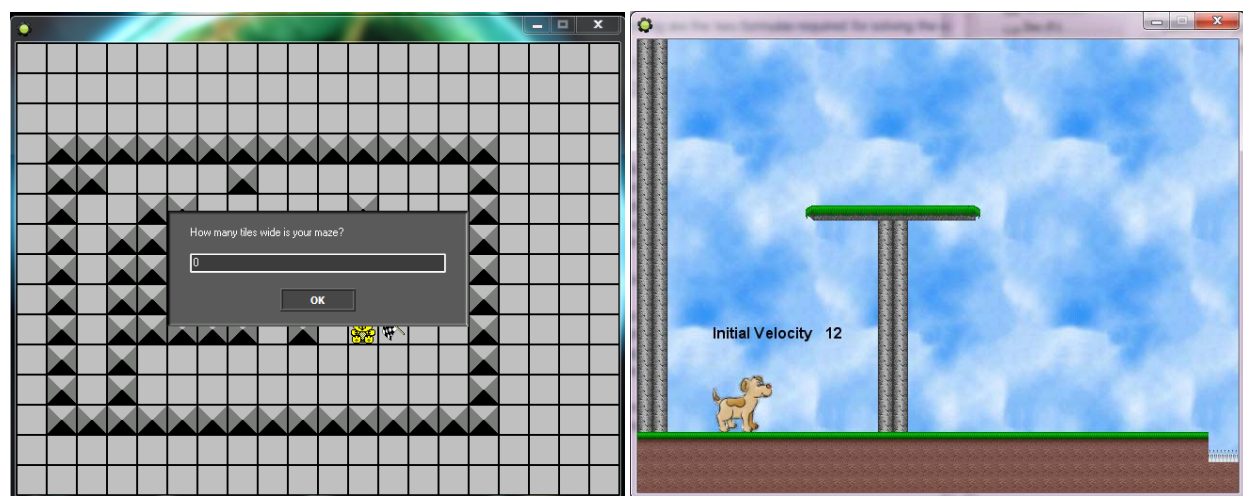


Figure 9a,b. Maze and Platform game math games.

## Teacher feedback

The different math strategies were implemented during the pilot and observed. To understand the teachers' perspective on challenges to student learning and teaching, teachers were asked the following questions regarding game development and game math.

- What are the challenges to learning math from game development?
- What are good strategies for promoting math for game development?
- What are the challenges to teaching math for game development?

Regarding game making, teachers reported that student engagement in games was positive but sustaining interest was difficult and challenging. Regarding game math, teachers remarked that it still needed to be integrated in a better way, and even that game making should be independent of the mathematics. The math instruction that was integrated into games, as opposed to math worksheets, and presented in front of class, as opposed to having students do on their own computers, was more engaging than paper-based individual instruction. However evaluation was a challenge because students did not take assessments seriously.

It was also noted that just because the math is put in a game design context did not necessarily make the math easier. One way teaching math through game development can be successful is if the students' enthusiasm for game development carries over to the math problems. One strategy would be to integrate the math well, so that the students want to solve the problem because it is necessary for them to proceed in the game development, as opposed to artificially adding the math as another obstacle in the game. Professional development time to integrate math into the game development process was requested for this purpose.

Assessment of mathematics learning in the new context has been hampered by students' feelings about not wanting to learn math and not wanting to take math "tests". There is also the burden of grading mathematics assessments, especially for teachers who are not math-credentialed. We are designing automatically graded online assessments that can be easily administered.

## Conclusion

It is evident that students enjoy game-making and that there are multiple paths to integrating mathematics into this context. The study is still in progress and we continue to assess strategies for embedding mathematics. It is clear that students engaged in the collaborative online activities, and that they preferred the integrated math games to the paper-based worksheets. We need to make the students' enthusiasm for game development effectively carry over to the math problems. We will continue to test and assess the strategies described here with the goal of keeping students engaged and motivated to study mathematics, and are currently exploring ways to better track student game design work so as to assess new strategies for math manipulation in the context of game-making.

## Acknowledgements

The worked was sponsored by National Science Foundation, Creative IT award #1002901. The program implementation would not have been possible without the commitment of film teacher Rajeev Talwani and mathematics teacher Mitsuyo Clark, and the support of LEMA HS Principal Roberta Mailman, and governing board Chair Beth Kennedy. The investigators wish to thank all the USC Pedagogical Games students who have contributed their amazing talents to the project.

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