Gaming Your Mathematics Course: The Theory and Practice of Games for Learning

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Synopsis

Learning through play is fundamental to humans and to many other animals. Game Based Learning is an interactive pedagogy that has as its foundation the tenet that games, by their very nature, increase learning through positive emotional experience. This article introduces readers to what games in mathematics classes have the potential to do, including to decrease anxiety, increase motivation, and deepen learning through immersive gaming. The article then connects this theory to practice, providing examples of both computer and non-computer games in introductory middle school, high school, and college mathematics. The article analyzes how these games work, and makes the distinction between *intrinsic games*, in which the concept being taught is an integral part of the game, and *extrinsic games*, which can be used for a variety of topics and tend to be more about review than about learning new concepts.

1. Introduction

Game Based Learning is an interactive pedagogy that has as its foundation the tenet that games, by their very nature, increase learning through positive emotional experience. Games do not merely entertain; rather, they can deepen connections and allow for greater learning. While educational video games are gaining currency, old-fashioned board games, card games, etc., can also offer pedagogically rich opportunities for learning mathematics. This article introduces readers to what games can do, then connects the theory to practice, providing examples of (non-computer) games in introductory college mathematics classes and how they work. The article ends with a look at some currently available middle, high school, and college video games.

2. The Need for Play

Learning through play is fundamental to humans and to many other animals. Yet, most mathematics is still taught in a traditional style, with teachers doing most of the talking and student participation at a minimum (see for example the 1999 TIMSS study [9]). Ask mathematics teachers why their students do not do well, and you will hear complaints that students come in late, leave early, do not do homework, and text message each other while in class. Rather than dismiss these as the usual cranky complaints of teachers facing a new generation, it is important to listen to the problems underlying all these complaints: the need for better student engagement, motivation, and attitude.

Then why has play not surfaced more strongly as an antidote for bored passivity? Perhaps it is because we erroneously see play as the opposite of work. Rieber, Smith, and Noah [15] explain, howewver, that serious play can involve hours of hard work and creative, higher-order thinking, to which we are more receptive because of the intense motivation involved. This is the paradox of play: We are willing to do even frustrating and difficult work because we are having fun. It is worth noting that these hours and hours of time are what cognitive psychology tells us it takes to move from being a novice to becoming an expert (see for example, [1]; or for a more popular description, [7]).

We can see this motivation effect in video game play. Students who groan at the thought of an hour of homework or give up in dismay at a difficult math problem often go home to spend hours playing complex videos games that involve constant calculating and planning. In the language of cognitive psychology, "...video games increase activation and arousal, which may improve task performance ..." [17, page 64]. Moreover, players easily pick up on all the problem solving strategies in gaming that we wish they used in the classroom: investigating through trial and error, following instruction booklet directions, sustaining their focus, and researching collaboratively (e.g., finding solutions online or through friends). As Mayo notes in *Science* [13, page 80], "Game-based tasks often require the formation of hypothesis, experimentation, and discovering the consequences of actions taken."

According to David Shaffer in *How Computer Games Help Children Learn* [18], video games are a powerful tool for learning because they allow us to create imaginary worlds in which we can become immersed – the immersion and flow state that Rieber *et al.* speak of as an intrinsic part of serious play.

Unfortunately, as mathematician Keith Devlin points out in his book on gaming in mathematics [5], video games for teaching mathematics are in the early stages of development. In addition, the games may not be suitable for, or accessible to, many mathematics teachers. Faculty who are new to gaming may wish to start smaller, with easy-to-play classroom games that may not bring students into the immersive state of serious play but certainly will improve their attitudes by associating mathematics with fun rather than fear.

Improving student attitudes is not an insignificant, frivolous achievement. Negative attitudes about mathematics, if not changed in college, may reverberate to the next generation of students. Some of the students who in our classes struggle with or even hate mathematics will soon be in the classroom teaching elementary school students mathematics and passing along the same attitudes. It is imperative, therefore, that these attitudes be changed now. Moreover, decreasing anxiety and negative messages about mathematics can result in increased student achievement, particularly for those who are susceptible to the negative stereotype that they cannot do math. For example, several studies, starting with Spencer *et al.* [19], have shown that women perform more poorly on mathematics tests when they are told that the test tends to show gender differences. These differences in performance were mitigated by researcher interventions which allayed the anxiety, even without addressing the cause of that anxiety [2].

It is my contention that one of the best ways to decrease anxiety and to change negative attitudes is to play games.

3. Examples of Games

3.1. Bizz Buzz for Base Systems

A simple game for learning base systems illustrates many of the connections between game based learning and other pedagogies. This game can be played in a class intended for liberal arts or elementary education majors. The game is a variant of *Bizz Buzz*, often played as a drinking game.

Students sit in a circle and count off – one, two three, four. The fifth person, instead of saying five, says "*bizz*." The count continues – one, two, three, four, *bizz-bizz*, then one, two, three, four, *bizz-bizz-bizz*. After the fourth such sequence, the count changes – instead of saying *bizz* five times, the counter says *buzz*.

This is a base 5 counting game, with $(10)_5$, or 5, represented by *bizz*, and $(100)_5$, or 25, represented by *buzz*. The game typically engenders much laughter as students who are not quite paying attention say 5 instead of *bizz*, or *bizz* instead of *buzz*. Students help each other to say the right word, "Say bizz!" they call out to the confused fifth person. But the game is not too hard, and soon everyone gets the hang of it.

Explicit connections can then be made between the game and the notation for base 5. For example, the seventh person is *bizz* + two = $(12)_5$ in base 5. The connection can also be made to base 5 manipulatives – units, 5-unit rods, and 25-unit squares. The game can later be played in a different base, to extend the difficulty level and to deepen understanding.

3.2. The Spread of a Rumor

This game introduces students to the concept of exponential growth. It can be played as the spread of a rumor, or the spread of a virus, and works well in an algebra or modeling course, in a quantitative reasoning course, or in a liberal arts mathematics class.

Each student gets a card, labeled "Round 0 ____, Round 1 ____ , etc." On one student's card, there is a *yes* next to round 0, while on the rest of the cards, there is a *no*. The student with a *yes* is the student who "knows" the rumor or who has the virus.

Students are instructed to stand up and mill around. In each round, they must look at one other person's card. If that person's card has a *yes*, the student who did not have a *yes* now has one, while everyone else writes *no* – without saying anything about which they have on their card. After enough rounds so that everyone has a *yes* (for a class of 35, this is usually about 6 rounds), students sit down and a chart is made of how many had a *yes* at each round. Connections are then made to doubling, and to powers of 2, which then leads to a discussion of exponential growth.

Note that the growth modeled here is actually logistic, since there is a limit to the number who will have the rumor or virus, but if the game is played only up to a certain number of rounds, it mimics plain exponential growth nicely – as does the spread of a rumor or virus in a large population. The game can later be played with different growth factors, such as introducing some amount of immunity (a person only gets the virus after being exposed twice, or three times) or increased virulence (each person shows two or three people their card, on each round).

The Spread of a Rumor can be seen as a simulation, rather than a game, although the distinction between a simulation and a game is often only a matter of semantics. However, for serious 18-year olds, it can be problematic to be seen "playing" – whereas older students and future teachers do not seem to mind as much. I usually introduce this one without saying the word "game."

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Although *Bizz Buzz* and *The Spread of a Rumor* teach different concepts and are used in different courses, they share many important characteristics. Both are *intrinsic games* (as defined by Malone and Lepper [12]). That is, the concept being taught is an integral part of the game; we cannot swap out the content and teach something entirely different with the game. In addition, both games teach new concepts rather than practicing an already learned one. Both games involve physical activity. Finally, both share the characteristic of a good game in that they can be played at increasing levels of difficulty/complexity, so that students can deepen their understanding through further game play.

The next two games described are *extrinsic games* – they can be used for a variety of classes and topics. The first game, *Hypothesis Test Bingo*, can be used to inject humor into any new topic in which the vocabulary is difficult and the concepts somewhat daunting. The second, *Test Review Jeopardy*, is a fun way to practice already-learned concepts.

3.3. Hypothesis Test Bingo

In the introductory statistics classroom, hypothesis testing is traditionally one of the most difficult units, filled with new vocabulary and difficult concepts (for example, "null hypothesis," "test statistic," "reject," "fail to reject"). To alleviate tension in the first class introducing this topic, I bring in bingo cards, with the vocabulary words randomized on it (search for "bingo card randomizer" to find a web application that will do this for you). Students are instructed to mark an X on the bingo card square when they hear that vocabulary word or phrase in the lecture – when they get 5 in a row,

H1 can be < or >	**Reject Ho if the sample mean is unusually *far* from the hypothesized mean.**	**You can never prove someone is innocent, only that they are not guilty.**	**If the probability is small**	**If the z-score is large**
Fail to Reject Ho	**Ho must have =**	**The sample mean or proportion will be *close* to the true population mean or proportion.**	**H1**	**original claim**
null hypothesis	**FREE BINGO SPACE!**	**Accept H1**	**sample**	**Reject Ho**
null hypothesis	**Ho**	**Reject Ho**	**alternative hypothesis**	**calculated z-score**
alternative hypothesis	**Ho must have =**	**test statistic**	**population**	**We are trying to use the sample mean or proportion to predict the whole population mean or proportion.**

Figure 1: Hypothesis Test Bingo, Front of the Card

they shout "bingo!" (See Figure 1 above.) To keep students focused not just on hearing the words, but also listening for the meanings, students turn the bingo cards over to work in groups on a matching exercise after the lecture is over (See Figure 2 below).

Vocabulary bingo can be played in any class where a large amount of new vocabulary is introduced. New concepts and vocabulary can often be bewildering and anxiety provoking. Bingo changes this dynamic – the laughter engendered by shouts of "bingo!" helps, as does working together to remember the words and their meanings in the matching part of the game.

3.4. Test Review Jeopardy

One of the easiest ways to incorporate games into teaching is to use *Jeopardy*. I have used this to liven up test reviews in courses as disparate as calculus and remedial arithmetic. Free templates for the game can be found by searching "PowerPoint Jeopardy Template." One then enters questions

Match the item on the left to the correct item on the right.

1. We are trying to use the sample mean or proportion
2. H_o is…
3. H_1 is …
4. H_o always has this symbol
5. H_1 always has this symbol
6. Reject H_o is the same as saying
7. We reject H_o when…
8. We fail to reject H_o when …
9. test statistic
10. Accept H_o.
11. You can never prove someone is innocent, only that they are **not guilty**. This is like how in statistics….
12. If H_1 has a < symbol, we have a ____ tailed–test.
13. If H_1 has a > symbol, we have a ____ tailed–test.

a. The alternative hypothesis
b. the mean in the sample is *far* from the hypothesized population mean.
c. Right-tailed test (note that the symbol points to the right).
d. Something we never do.
e. the mean in the sample is *close to* the hypothesized population mean.
f. You can never prove the null hypothesis is true, you can only say it's false (reject H_o) or **not** false (fail to reject H_o).
g. Left-tailed test (note that the symbol points to the left).
h. The null hypothesis
i. =
j. to test a claim about the whole population mean or proportion.
k. < or >
l. H_o is not true
m. The z score we calculate

Figure 2: Hypothesis Test Bingo, Back of the Card

and answers into the template. There are also versions available that teachers have posted for various classes, with the questions and answers already written in.

To make game play more collaborative, and to ensure that everyone is working, the whole class can participate in finding the answer to each question, rather than just one student at a time, or the class can be split into teams. Students appreciate being able to go back over the game at home as further review, which can be facilitated by posting the game online.

This game is a review of already learned concepts. The pedagogical advantage over review sheets is that students enjoy it more, but at its heart, this game is really just an animated test review sheet. In that regard, it is similar to most commercially available educational video games.

4. Current Mathematics Video Games

It is difficult to find innovative video games at the middle school, high school, or college level. As Gunter, Kenny and Vick write, "We are witnessing a mad rush to pour educational content into games in an ad hoc manner in hopes that player/learners are motivated simply because the content is housed inside a game" [8, page 511]. The games they describe in this quote are those previously described in this article as extrinsic games, the games that are like animated test reviews, jazzed-up quizzes.

4.1. DimensionM and Brain Training

One game that has gotten much press lately is *DimensionM*, a video game for middle and high school pre-algebra and algebra. New York 1, the local city news channel, reported excitedly in April, 2010 that, "thousands of city students have become hooked on *DimensionM*, a role-playing video game that requires quick math skills to keep going" [4]. In *DimensionM*, students capture correct answers to questions and accrue points, all while navigating a new planet as space explorers. The game is well-designed, it feels realistic, and the questions are fun. The game does not, however, allow for deep knowledge creation, and it is not about learning as you play – it is about practice, since the players must already know how to get the answers before they start game play.

Increased practice time, however, is no small achievement – there is a large place in mathematics for the acquisition of basic skills through practice. Preliminary results in an unpublished doctoral dissertation, which studied 981 algebra and pre-algebra math students and 10 math teachers from an urban high school in the southeast United States, suggest significant post-test differences between the treatment group (students who played *DimensionM*) and the control group (students who did not), based on scores on the district-wide exam [11].

A recent study in Scotland found that students who spent the first twenty minutes of school every morning playing Nintendo's *Brain Training* showed similarly positive results, with far greater improvement in math than the control group which did nothing differently [20]. *Brain Training* is a game played on the hand-held Nintendo DS; it features reading tests, memory games, and arithmetic challenges. The study, conducted by Scotland's public research and education body and the University of Dundee, involved 600 children in

32 schools. However, a subsequent study in France of 67 children had the control group do pencil and paper puzzles. In this study, the Nintendo group did no better in math [16]. These results point out the need to investigate video game learning properly, with meaningful control groups. They also show that, as with *DimensionM*, practice does help – and there is certainly something to be said for making practice more fun.

Yet, computer games have the potential to do so much more. According to David Shaffer in *How Computer Games Help Children Learn* [18], video games are a powerful tool for learning because they simulate reality, allowing us to create imaginary worlds and identities. But this identity is not just constructed to allow us to shoot the correct answers, but rather, to help us learn to solve the problems associated with that identity. For example, a game player can experience being a mathematician, not just by imagining that she is one, but by immersing herself in the language, structure, and actions of that field. Such immersion, says Shaffer, endows the work the player does with a deeper, epistemological meaning. Taking on the identity of a learner (or a doer) in order to encourage deeper learning is also a key concept in James Gee's groundbreaking *What Video Games Have to Teach Us about Learning and Literacy* [6]. Or, as Devlin explains, "…doing mathematics means thinking like a mathematician" [5, page 58] – which means not just procedural fluency of the type encouraged by *DimensionM* and *Brian Training*, but also conceptual understanding, strategic competence, and more.

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The next games encourage all these things, and show what good, middle school through college-level video games have the potential to achieve.

4.2. Ko's Journey

Ko's Journey is a game for middle schoolers that stands in sharp contrast to *DimensionM*. In it, players follow the adventures of a girl who has been separated from her family and must travel across the wilderness. Along the way, she must solve problems using mathematics, including finding the correct proportion of medicinal plants to save a wolf cub and the correct angle to shoot her arrows. Identity and intrinsic mathematics are key components of the game. Moreover, the game tells an absorbing story, which is a component of game play that some theorists feel is essential to deeper learning [8].

4.3. NUI-Torcs for Numerical Methods Classes

NIU-Torcs is a rare example of a college-level game that allows for deeper mathematical learning within the game. Brianno Coller and colleagues developed the game through an NSF grant to help their mechanical engineering students learn numerical methods [3]. Students begin the game by learning how to code acceleration and steering using the programming language C++. As with any good game, these first tasks are relatively easy. According to the authors, "We have invited high school students on campus to play the game; they are able to do it, usually within an hour or two. Making the car move fast and nimbly without skidding off the road, however, is a challenge that takes nearly fifteen weeks to fully realize." To do the latter, students must calculate numerical roots, solve systems of linear equations, and be able to do curve fitting and simple optimization. The authors report that students are motivated to keep trying far more than when given these types of problems as meaningless homework exercises. Moreover, the students are involved in authentic work that allows them to begin thinking and acting like real engineers, creating the "identity" and the real-world connections that researchers like Shaffer find so important. Concept maps produced by the students in both the game-based and traditional classes showed that although measures of low-level knowledge were statistically identical, students in the game-based class had much greater levels of deep thinking, which included being able to compare and contrast methods and link concepts together. In addition, students' attitudes about the class had changed – they were more engaged, and more able to recognize the value of the mathematics they were doing.

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In both *NUI-Torcs* and *Ko's Journey*, procedural competency and problem solving skills were interwoven. The games are both intrinsic – the motivation to play and learn comes from the structure of the game itself.

4.4. Lemonade Tycoon

A good example of a game with strong identity formation and mathematical teaching is found in the game *Lemonade Tycoon*, played by middle-school-age children up through adults. The object is to sell lemonade for a profit by adjusting the price, ingredients, customer wait times, and more, as the weather and other outside factors change. *Lemonade Tycoon* won the

Pocket PC Magazine's Best Pocket PC Strategy Game award in 2002. This commercially successful game uses business variables like price and customer satisfaction and allows players to explore the economic and mathematical concept of optimization. A smaller, free version, *Coffee Stand*, can be found at http://www.coolmath.com (accessed June 12, 2012).

Unfortunately, the game points to a problem with some intrinsic games for mathematics: The mathematics is subtle, and implicit, interwoven through the game, so it does not transfer well into a math class. For example, although optimization is an important part of the game, play would be seriously interrupted if students had to stop to write the calculus equation involved. Players are not even required to keep track of their inventory through multiplication or subtraction – the game does this for them. An enterprising business calculus professor might, however, use the game as an introduction to optimization, perhaps challenging the students to beat the game by writing the correct series of equations. Some writers (e.g., Shaffer, Devlin) feel that the problem here is not that these sorts of games do not fit the mathematics class well, but rather, that mathematics classes (and, according to Shaffer, school subjects in general) do not fit well with the way we learn best, which should involve more experimentation, less routinized procedure, and more deep problem solving. No matter which side one comes down on this age-old debate, it is clear that some of the best games will not mesh well with core competencies and standardized tests. This may be why the game that is currently so popular, *DimensionM*, is an extrinsic game that helps students practice getting answers quickly rather than problem solving. For a closer look at schema that apply specifically to video games, please see my article [14].

5. Conclusion

We have seen what both extrinsic and intrinsic games have the potential to achieve: at minimum, decreased anxiety and increased practice time; at best, immersion into the principles and language of a field of learning, so that a deeper appreciation and understanding of mathematical principles can be achieved. Games like *Bizz Buzz* and *Bingo* can introduce a topic in a way that minimizes anxiety and deepens understanding, while drill and practice games like *DimensionM* can encourage students to put in the practice time that allows them to become experts. Some intrinsic games, like *Ko's Journey* and *NUI-TORCS* can allow for both knowledge creation and increased practice.

The advantages of serious games can occur whether we play them on computers, or sitting in a circle, counting by fives. They can occur whether we wholeheartedly launch ourselves into gaming our entire curriculum, or just want to try adding a few, well-placed games. Far from being distractions or time-wasters stealing valuable time away from the curriculum, games can be an integral and important part of learning.

Faculty who wish to begin to explore using games in their classrooms can find support in this endeavor through educational websites like the CUNY Games Network.[1] The *CUNY Games Network* connects educators from every campus and discipline at the City University of New York who are interested in games, simulations, and other forms of interactive teaching. Guests from other campuses are also welcome. Other sites of interest are EdWeb[2] which is a networking site for educators that has a group on gaming, and Math Future[3] which is an excellent place to connect with educators interested in different forms of innovative mathematics education.

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