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Research Article

Digital Games for Future Math Teachers: Transforming Undergraduate Education

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Abstract: The growing field of game-based learning has opened up a rich channel to convey content and to examine teaching and learning in a critical way, one that we believe can be useful for teacher preparation in all subjects. As college mathematics professors, we examine how digital games, even ones meant for young children, can help our college students learn content. With the topic of fractions, an area that often frightens our pre-service teachers, our results show gains between pre and post test with game play alone (no teaching of the material) and even larger gains of over 15 percentage points from pre- to post-test when students played the game and discussed the concepts in class. Our work using games with pre- and in-service elementary education majors also shows that students can use games not only to learn subject material, but also to think critically about how to use games with their own students when they become teachers. We share a survey tool, EduMAp, that we developed as a means to facilitate this critical thinking, and the results of using this tool in a workshop with teachers, and in our graduate education class. EduMap was designed for mathematics apps, but can be adapted to critique apps in other disciplines as well. Qualitative results show that students change how they think about games in learning over the course of only a few lessons, using the EduMap tool as a framework.

Keywords: Mathematics,digital games,higher education,preservice teachers

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1. Introduction

The growing field of game-based learning has opened up a rich avenue to convey content and to examine teaching and learning in a critical way, one that we believe can be useful for teacher preparation. As mathematics professors and teacher educators, we hope that STEM faculty in particular will find inspiration in and practical uses for our work in game-based learning, but we believe it will be useful to educators of pre- and in-service teachers across many disciplines.

In using digital games to teach content, we draw on a body of emerging research that shows the efficacy of games in education as a way to increase engagement. Games place students in what Johan Huizinga (1955) called "…the magic circle…temporary worlds within the ordinary world, dedicated to the performance of an act apart." (p. 10) This suspension of ordinary rules can create a safe place to explore what might otherwise seem difficult or frightening. In modern-day behavioral scientists' terms, "…video games increase activation and arousal, which may improve task performance" (Schmidt & Vandewater, 2008, 64).

In addition to using games to help students learn content, we seek to use games in a new way: as texts, to be "read" critically as a valuable window into how to teach, how to convey multiple concepts in a variety of ways, and the difference between exploring new concepts and drilling old ones. Through this lens, we help our students understand the new Common Core State Standards for Mathematics, which have been adopted by 46 states in the United States as their learning and assessment standards. We also use game-based learning to help reteach our students some important grade school mathematics topics, like fractions.

This article presents first an overview of the evidence for game-based learning, and then our own results, both qualitative and quantitative, using games to teach college students. We then detail how we created EduMAp, and show how it can be used as a framework for teaching students how to evaluate digital games.

2. What is a Game? Terms and Definitions

2.1. An Academic Definition of Games

Games are belief engines. Games are canvases for stories in motion. Games are a challenge and a learning activity. Games are ideas. Games are explorations both intellectual and meaningful. Games are positive. Games make life better. Games help you feel success when all around you is grey and confusing. Games are change. Games are illuminating. Games are insightful. Games are irreverent. Games are very old. Games are very new. Games are tests. Games are addictive. Games are pressure. Games are motivational, inspirational and educational. Games are fun. Games are exercise. Games are good for body and soul. Games are about you. Games are projections. Games are worlds which we superimpose on this world in order to escape or make sense of it. Games are dynamic, chaotic and delightful. Games are there to be mastered, used up and then forgotten. Games are participatory, cultural and shared. Games are demanding. Games are emotive. Games are sometimes indescribable and yet all too real. Games are made, but more than the sum of their made parts. Games are a constant source of the strange. Games are risky. Games are playful. Games are one of the key experiences that life is for. Games are brilliant. Games are an art form. Games are numinous. Games are thaumatic. Games belong to us.

This delightful passage, an invocation of all that games can be, comes from Tadhg Kelly, a game designer and journalist who writes for leading game industry magazines and websites such as TechCrunch, Gamasutra, and *Edge* magazine (Kelly, 2014). We agree that games can be all these things; although we did not grow up with digital gaming as it is today, we grew up playing games. Moreover, we see our children and our students immersed in games, and understand that the idea of what a "game" is can be this broad and all-encompassing. However, less idealistically and more critically, we wanted to see whether a more precise definition would help us in our academic work with games.

In 2004, Katie Salen and Eric Zimmerman, game designers and academics in the nascent field of game design, wrote the book, *Rules of Play*, "to provide critical tools for understanding games." To begin the discussion, they analyze eight theorists, from Huizinga in 1955 to Parlett in 1999, who have attempted to define the term "game."

Their own definition, which takes elements from many of the theorists, is that, "A game is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (pg. 80). They point out that this conflict, or "contest of powers," can be cooperative or competitive, involving social conflict against other players, or solo conflict against the game system. "The key elements of this definition are the fact that the game is a *system*, *players* interact with the system, a game is an instance of *conflict*, the conflict in games is *artificial*, *rules* limit player behavior and define the game, and every game has a *quantifiable outcome* or goal" (pg. 80). They also note that the game is a safe place within which to have this conflict, with limited and certain consequences. This echoes Huizinga's idea that one of the defining elements of a game is that it creates a "hallowed" space apart from ordinary reality, "...within which special rules obtain" (1955, 10).

2.2. Gamification as Separate from Games

The act of *gamification* is also worth mentioning here, since it is sometimes seen as identical to creating a game; however, the definition of gamification (see for example, the online Oxford Dictionary, 2014) is that it uses elements of a game – point, badges, dice, and so forth. In our teaching experience, just the presence of brightly colored game pieces can lighten the atmosphere in a classroom, but this is not the same as creating an entire game *system*, with rules and a quantifiable goal or outcome.

2.3. Digital game/video game

Finally, we note that use of the term *digital game* has gradually been replacing the older term, *video game*, as gaming platforms have changed from being largely computer, television and console-based to encompass hand-held devices, including cell phones, tablets and other mobile devices.

2.4. Chocolate-covered broccoli

Of course, none of these definitions answer the question, what is a good game; or, more particularly, what is a good *educational* game. In fact, bad games in education are so common that the term, "chocolate-covered broccoli," has been coined to describe games, which merely seek to disguise dull content with a sweet confection. Yet games have the potential to do so much more, as we describe below.

3. Digital Games in K-12 Mathematics Education

In his groundbreaking work, *What Video Games Have to Teach Us about Language and Literacy* (2003), James Gee details 36 video game learning principles. Among them are active rather than passive learning, learning in a risk-free environment, and large amounts of practice, with multiple routes to success. As Keith Devlin points out in *Mathematics Education for a New Era* (2011), these are all elements of learning that we wish were available to all children when learning math. Devlin believes that video games can provide an experiential way to learn mathematics, in which a student learns through exploration rather than memorizing rules, something that he says can be difficult to provide in a classroom. We contend, however, that it can be quite difficult to provide in a game, too, with many math games simply repeating the skill and drill method often favored by teachers and parents.

Gee also argues that video games are a powerful tool for learning because of the way in which they can deliver information just when it is needed, with feedback built-in to the structure of the game. A good game, he says, keeps the player in a state of "pleasant frustration." This state Gee describes is akin to the "zone of proximal development," a term Vygotsky coined long before video (or digital) games, to describe that ideal mental place in which a learner needs only some guidance to keep learning (1979). Moreover, digital games have a potential advantage that Vygotsky could not have anticipated: the microchip-enabled automation and adaptability.

Yet beyond the hype about what video games have the *potential* to do, up until recently, there was little actual evidence that video games improved learning. Robust empirical research involving pre-test, post-test, and control groups has been scarce (Westbrook & Braithwaite, 2001; Hays, 2005; Young, Slota, Cutter, Jalette, Mullin, Lai, & Yukhymenko, 2012). Nicola Whitton, in her recently published *Digital Games and Learning* (2014), contends that pre- and post-test may miss deeper learning, such as synthesis, creativity and critical thinking, so she argues for a mixed-method approach including communication between learners, and assessments of how learners are structuring their knowledge.

All of this is a tall order in education, where large-scale studies are often difficult to finance and organize. Even so, a body of work from all over the world is emerging that shows positive, statistically robust evidence for learning through digital games. For instance, Vogel et al. (2006) found that students whose instruction was supplemented with computer simulations and games "report in their meta-analysis of games in education found higher cognitive gains and better attitudes toward learning compared to those using traditional teaching methods" (237). Video games may also improve problem-solving skills, broad knowledge acquisition, motivation, and engagement (Perrotta, Featherstone, Aston & Houghton, 2013).

In mathematics, several promising studies have recently emerged. Keeping in mind that the field is emerging, we present findings from several different countries and various age groups.

In Chile, a study published in 2003 (Rosas et al., 2003) of 1274 students from disadvantaged schools showed significant gains in first and second grade math scores for those who played math video games over the control groups who did not, controlling for pre-test scores and abilities. The researchers designed the games themselves, and used a hand-held device that would be affordable for the school. Students played for 20 to 40 minutes daily for 12 weeks. On the qualitative front, teachers reported high motivation from the gaming group, noting that behavior improved, with more students coming to school on time because they were eager to play the game.

A study of over 600 students in Dundee, Scotland (Fernandez, 2008), found that students who played Nintendo's *Brain Training* for 20 minutes every morning at the start of school showed far greater improvement in math than the control group, which did not play the game. *Brain Training* is a game played on the hand-held Nintendo; it features reading tests, memory games and arithmetic challenges. Improvements were also found in concentration and, as with the Chile study, in behavior and in decreased absences and lateness. The drawback to the methodology in this study, which has not yet been published in a peer-reviewed journal, is that it does not seem as if the children in the control group engaged in similar mathematics activities *without computer games* – the article only vaguely states that they continued with "traditional" school activities. In a subsequent French study of 67 children, where the control group did paper and pencil puzzles, the Nintendo group did no better in math (Sage, 2009).

In Greece, Sampson and Panoutsopoulos (2012) studied the use of a commercial game, "Sims--2: Open for Business," at a private school in Athens. The researchers examined 59 students ages 13 to 14 for both attitude and test scores. In this study, researchers did create an equivalent activity for the control group, without the game. Thus, students in the control group also selected an imaginary enterprise to run, hired employees and set prices for products. The results were nearly identical for both groups in math subject-matter outcomes and attitudes, but the game-based group outperformed their counterparts in the general objectives of being able to formulate hypotheses, compare and contrast data, and justify their results. As the authors write, "Supporting game-based activities with appropriately designed worksheets provided the necessary structure and allowed for reflection" (p. 25). Thus, this study not only shows the value of games for higher order thinking, but also showcases a particularly thoughtful and reflective way of using a game in a classroom.

Finally, another study, also in the United States, looked at type of game play. The authors (Ke & Grabowski, 2007) found that of 125 fifth graders in Pennsylvania, those who played the *ASTRA Eagle* math games cooperatively showed the most gains on a state test, followed by those who played it competitively, and then those who did paper and pencil math drills. The cooperative game play also was most effective in promoting positive attitudes about mathematics. Attitude was not mediated by gender, but social economic status was a factor – with students of lower SES backgrounds showing more gains in attitude in the cooperative version of gameplay. The games played in this study were strategy and problem-solving games.

In conclusion, the field of game-based education, particularly as it pertains to the teaching of mathematics, is so much in its infancy that to find enough rigorous studies for this review, we have had to examine studies from several countries, with students of all different ages, from varied economic backgrounds. Game play in these studies ranged from competitive to collaborative, and many types of games were involved – commercial games, games designed specifically for the students, quiz-type skill games, and games that support higher order thinking. Most results were positive, but it is quite likely that there is confirmation bias at work here, the tendency for authors and publishers to only publish studies with results that confirm and support their own suppositions or the prevailing wisdom. All we can say for certain from this set of studies is that, yes, it is *possible* for a K-12 classroom game to improve attitudes about mathematics and to support and improve various types of mathematical understanding.

4. Digital Games in Higher Education Mathematics

Research on the efficacy of digital games in higher education has lagged far behind the research in elementary education. This is despite the fact that video games are a common part of nearly all (97%) teens' lives, with most playing on a regular basis, according to a 2008 study by Lenhart, Kahne, Middaugh, Macgill, Evans &Vitak, sponsored by the Pew Internet and American Life Project. This study also found that video games are played by both girls and boys, and across all socio-economic backgrounds. Prensky (2001) contends that the reason why video games offer a powerful medium of instruction for today's learners is because post-Baby-Boomers are "digital natives" whose brains are physiologically different from previous generations due to repeated exposure to digital media in their formative years; consequently, they thrive when exposed to learning environments that provide the multi-modal, feedback-rich elements endemic to video games.

In one of the few published studies on math games in higher education, Coller and Scott (2008) describe having numerical methods students playing *NUI-Torcs,* a simulation game that involves racing a car around a track by learning how to code acceleration and steering using the programming language C++. 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 were motivated to keep trying far more than when given these types of problems as context-less homework exercises. Although measures of low-level knowledge were statistically identical, concept maps produced by the students in both the game-based and traditional classes showed that 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. Coller and Shernoff (2009) further report that students taking the game-based course were more engaged in their homework than students involved in other engineering coursework.

Mayo (2009) posited several reasons why video games are not readily available in STEM education, including "...the lack of any distribution mechanism for the product, the lack of product discoverability, the prohibitive expense of content creation, the dearth of meaningful assessment (and therefore of consumer confidence in the product), and the lack of sustainable business models" (p. 80).

Because of this difficulty in getting digital games into the college classroom, we also include in this review a study of 140 community college math students (Crocco, Hernandez, & Offenholley, in press) that examined the use of hands-on (non-digital) games in mathematics classes. Each professor gave a game-based lesson to one class, and a lesson without games to their other class. In all cases, the game-based classes showed higher enjoyment than the control group of non-game-based classes, with 61.3% enjoying the non-game lesson to 76.5% enjoying the game-based one. In post-lesson quizzes it was found that increased enjoyment correlated positively with improvements in deeper learning questions that focused on the application of knowledge. However, overall scores on these quizzes were statistically identical.

As with the studies on games in K-12, we have extremely disparate populations – engineering students in one study, community college students in the other. We also have extremely different types of games, digital versus hands-on. Yet we do see some common threads emerge: games can help college students have a more positive attitude about mathematics, and games can facilitate deeper learning, an increase in connections made, problem solving. As Gee, Devlin and others have said, there is great potential here – to which we add: *provided it is done right*.

5. The Need for Better Mathematics Education

There is no question that there is a need to improve students' mathematical abilities and attitudes about math, both in K-12 and in college mathematics. The 2009 Program for International Student Assessment (PISA) results show that although US 15-year olds performed similarly to students in other counties in reading and science, in math they were quite a bit below average, with only 27 percent of U.S. students scoring at or above proficiency level 4. Level 4 is the level at which students can complete higher order tasks such as "solv[ing] problems that involve visual and spatial reasoning...in unfamiliar contexts" and "carry[ing] out sequential processes" (Organization for Economic Cooperation and Development, 2004, p. 55). Twenty-three percent of U.S. students scored below level 2, described as "a baseline level of mathematics proficiency on the PISA scale at which students begin to demonstrate the kind of literacy skills that enable them to actively use mathematics" (OECD 2004, p. 56).

In college mathematics, we see a vicious circle – our students arrive underprepared in mathematics, this lack of preparation often accompanied by a fear or dislike of mathematics. They then go on to become teachers who are underprepared in mathematics, and thus fail to teach the mathematics well to their students. Liping Ma (1999) writes that U.S. teachers fare poorly when compared to their Chinese counterparts in such activities as employing the division of fractions algorithm, in explaining the mathematical reasoning embedded in the algorithm, or in giving a proof as to why it worked that way. Mewborn (2001), in writing about teachers' content knowledge, agrees, saying that teachers are often able to perform mathematical computations without being able to provide conceptual explanations for the procedures they use. For example, they may rely on how the system of whole numbers works to explain how fractions work, and also may make such mistakes as confusing the concepts of area and perimeter. Moreover, Mewborn writes, the literature suggests that although elementary school teachers are better able to perform calculations than their pre-service counterparts, not much changes in their ability to explain mathematics from when they are college elementary education majors to when they become teachers.

6. Incorporating Games in College Mathematics Education Classes: Two Studies

In incorporating games into our own college classes, we had several goals in mind:

1. We wanted to teach our students essential mathematics, and help them understand it more deeply. We wanted to examine more closely the best way to do game-based learning in the classroom.
2. We wanted to model the use of games in the classroom, because we believe that *experiencing* how learning can occur through a game is more effective than only reading about the advantages of game-based learning.
3. We wanted to help our students learn to think critically about games, so that when they become teachers, they will be more likely to choose games carefully, with pedagogical goals in mind, rather than merely choosing a game because it seems fun.

In the next section we describe two studies detailing how we achieved these goals. The first study addresses our first goal. It describes two different approaches to teaching fractions content using games, and the quantitative evidence for which worked better. The second study describes our process in creating a mathematics game evaluation tool and how we used that tool in the classroom to achieve goals 2 and 3.

6.1. Study 1: Learning Content through Games

Our first goal was to examine how to use games to teach our students essential mathematics, in this case, fractions. *Refraction* is a fraction game created by a team of graduate and undergraduate students at the University of Washington Center for Game Science under the leadership of Zoran Popovic as a part of a larger games for learning project. Each level of the game is played on a grid and consists of laser sources, target spaceships, and asteroids (see Fig. 1). Each spaceship needs a target fraction of the lasers, indicated by the yellow number on the spaceship.

Figure 1. Refractions

The laser comes out at a power of 1; using valves and splitters a player can make a laser at ½, ¼, 1/3, 1/6, 1/8, 1/9 and 1/12 of that power. Valves help direct the laser to the space ship so that players area learning how to break up a whole. As players move through the game, the problems get harder: the initial laser no longer has a power of 1 but a fractional power. To combine lasers, players must get a common denominator by using expanders that can multiply the fraction by 2/2, 3/3, and 5/5.

The game was designed for students from 2nd grade through middle school, but also for anyone working on skills and understandings with fractions. As our adult students progressed through the levels, they played at higher and higher 4r grade levels. Thus, *Refraction* is an excellent game to use to teach fractions to college students who want to become elementary school teachers, because it develops so much understanding of fractions, yet begins at an easy level.

6.1.1. Method

One of us (name blinded) explored how this game could be used with 37 students recruited from two sections of a mathematics education course for elementary school teachers. The students were pre-service and in-service elementary education majors. This course was the only mathematics course that they would be taking in their program, so learning both mathematics content and pedagogy had to happen in the same course.

The study examined whether classroom support made a significant difference in the effect of game-based learning of fraction equivalences and operations. Students took a pre-test on fractions prior to playing the game and prior to any coursework related to rational numbers. In section A, students were asked to play the online game, Refractions, for two hours at home. They completed this assignment before the rational number unit began in the middle of the semester. In section B, students were also asked to play the game for two hours at home, but this occurred while the course was focusing on rational numbers, equivalent fractions and fraction operations. At the end of the course, students from sections A and B both took a post-test on fractions. Both pre- and post-tests focused on fraction concepts as well as algorithms.

6.1.2. Results

Students from both sections generally showed some improvement in the pre- and post-test scores. To compare the change between sections A and B, a simple t-test was run comparing the differences in students' scores from their pre-test to their post-test. Table 1 summarizes the data from the comparison.

Table 1. Refractions Results

Group A (Game alone)	**Group B (game during fraction lessons)**
Mean improvement between pre and post test = 1.02722	Mean improvement between pre and post test = 3.09632
Standard Deviation = 2.04182	Standard Deviation = 3.37112
Standard Error = 0.48126	Standard Error = 0.77339
N=18	N=19
Two tailed t-test, Conservative df = 17; p=.03137	

Students in both groups showed a significant gain in understanding of fractions, with a p-value of 0.031. Among those in group A, those who played the game without instruction, the mean improvement was 1.0 point on a 20-point test, a gain of 5%. Students in section B who played the game while learning about fractions in the course gained an average of 3.1 points, an increase of just over 15%.

The standard deviation for group A indicated a spread of scores with most students improving between 0 points (no improvement with the game alone) and 2 points or between 0 and 10%. In group B, the spread was larger, indicating that most students improved between 0 and 6 points, or between 0 and 30%.

6.1.3. Discussion

Group A students, using the game alone, did show some improvement in scores, with an average increase of 5%. However, combining game play with classroom discussion and instruction showed much higher gains, on average. In addition, contrasting the standard deviations and spread of the two groups shows that in group B, some students were able to bring their scores up quite a bit higher, as much as a 30% gain. These results show that improvement is possible with game play alone, but is much higher when game play is alongside class discussion and instruction. These results are in line with some of the studies in our literature review, which use time for reflection on the game content as an integral part of teaching with games. We believe that this is particularly true when the game and instruction focus not just on rote use of routines, but also on seeking to foster understanding. That is, simultaneously learning through games and in-class instruction is more effective for deeply learning essential mathematics than is game play alone.

6.2. Study 2: Thinking Critically about Game Use in the Classroom

The rapid growth of mathematics apps for elementary school-aged children is the impetus for the second branch of our work. Apple (Rao, L., 2012) has reported that there are currently 20,000 education and learning applications for the iPad, and we ourselves have noticed that the growth of apps has been exponential, while guidance for teachers and parents has been scarce. Thus, we came together to begin working on an app evaluation tool and to test its use as a tool to help our students think critically about games.

6.2.1. Developing the EduMAp Tool

As teacher educators, it was important to us that we not just teach using games, but also provide students and teachers a way to analyze games critically. To this end, we developed the EduMAp survey tool. This tool was created using the current research on learning mathematics as well as learning through games. In particular, we referred to the habits of mathematical proficiency as defined by Adding It Up: Helping Children Learn Mathematics, (2001). These habits address areas of procedural and conceptual understanding and fluency, mathematical reasoning and problem solving and strategic thinking. Additionally, the EduMAp tool was designed to address features of game play such as speed, time for a turn, and team or individual play. These aspects are all important in judging whether the game could be useful in a classroom setting.

We spent nearly a year refining the tool. We tested it with our students and within our research group. Our goal was to make sure that the tool helped a user to evaluate a game in terms of learning objectives, support for higher-order thinking, and game mechanics that supported those learning objectives.

We were fortunate enough to be able to assess our tool with a wider group of educators, at the National Council of Teachers of Mathematics (NCTM) research pre-session on April 16, 2013. With over 20 educators present, we asked participants to review one or two apps from a list we provided, using EduMAp. Most were able to complete reviews of two of the apps. Participants then convened in small groups (according to which app they decided to review) to discuss the tool. We gave them a group feedback sheet with the following four questions:

1. Does the tool allow you to express your thoughts about the app? If not, what areas could be added to help with a full evaluation?
2. Was there a question or questions where your group differed significantly in their evaluation?
3. Was the topics list user-friendly? Should anything be added or taken out?
4. Is there anything else that should be added to the survey?

Feedback was collected in writing, through observation of the groups, and through a Q&A at the end that involved all participants.

Two of the four groups commented that they would have liked questions on game quality, such as, “Is it fast moving, engaging?” and whether or not the game was “intuitive,” or easy to use, including “frustration level” and “fun level.” This piece of feedback helped us to add the question, “Was it a fun game for **you**?” to the survey, because respondents clearly wished to express their personal opinions on each game.

In addition, groups commented that they still had questions about the game itself that would require more time and exploration. As the presenters (names blinded) walked around the room, we noted that talking about the game in groups caused many reviewers to change or deepen their thoughts about a game. For example, one group wrote, “We had varying experiences as different players chose different levels of difficulty.” Thus, we could see that the tool worked well as a springboard for further conversation and exploration of not only the game itself but also the mathematical content. Another group wanted to fill out the survey together, which we realized could be an optional way to use the tool.

Workshopping EduMAp in this way allowed us to create a much more robust tool for classroom use. The final version is below, fig. 2.

1. Was it a fun game for you?

☐ No fun ☐ Somewhat fun ☐ Fun ☐ A lot of fun ☐ Fantastic

Questions 2 and 3 used the scale:

☐ Never ☐ Rarely ☐ Sometimes ☐ Often ☐ Always

2. Goals and Outcomes I:
   a) Quick fact recall is required
   b) Random guessing leads to success.

3. Goals and Outcomes II:
   a) Skills are strengthened with more play.
   b) Logic and reasoning are encouraged.
   c) Strategic thinking is useful for best moves.
   d) New mathematical concepts are taught.
   e) Efficiency with basic common mathematical procedures is developed.

Questions 4-6 used the scale: ☐ Yes ☐ No ☐ Unsure ☐ Not Applicable

4. The app enables…
   a) timed play
   b) untimed play
   c) variations for repeated play

5. Features of the App
   a) Rules are given
   b) Hints are given
   c) Answers are made available
   d) Solutions (steps toward answer) are provided
   e) Correct answers are shown after 1 or more incorrect player response(s)
   f) Player score is recorded for future reference
   g) Multiple player scores can be kept
   h) There are different pathways to the end of a turn or end of the game
   i) Problems become more challenging as game progresses
   j) Player can stop the game/app and resume at the same point at another time
   k) Game/app has multiple levels
   l) Player can skip levels

6. Options for social play
   a) This app is primarily for an individual player
   b) This app encourages social play through competition, collaboration, and/or communication
   c) This app can be played online with other players

7. Options for play time (check all that apply):

☐ 0-5 minutes ☐ 5-10 ☐ 10-15 ☐ 15-20 ☐ More than 20 minutes

8. (Optional) Briefly describe the context of the game/app. Is there a character or characters? Is there a story as backdrop for the game/app?

9. (Optional) Briefly describe the mechanics of a turn in the game/app. What does a player have to do?

10. (Optional) Please provide any additional comments you have.

Figure 2. The EduMAp Tool

In addition to the above questions, our tool also includes a checklist of common core standards that are based on the Common Core Standards in Mathematics (2010), and provides a place for the reviewer to write their name and teaching background, and the price of the app.

Refining the tool in this way has allowed each of us to use the tool with pre-service teachers, as a springboard for the critical analysis of games, as described in the next section.

6.2.2. Using the EduMAp tool in the Classroom to Encourage Critical Thinking About Games

In working with pre-service elementary education students, we began to look at games as one curricular aspect of teaching mathematics. Our goal was to help students see the mathematics involved in the game as well as the pedagogy of teaching mathematics with the game as the context.

A class of 24 graduate students in elementary education began to explore games during the middle of their semester. Prior to taking this course, these students had taken some foundation education courses and literacy methods courses and one mathematics content course. To study student development over the duration of the two-day lesson, we collected qualitative data, looking at student responses as recorded on the Smartboard.

Class began with an open-ended question about what games could be played in math class and why. Student responses included: Chutes and Ladders for counting a long a number line, Ken-Ken, and Sudoku.

We can see from these responses that there is already some sophistication here. Although some students suggested the obvious, games that already have numbers in them, the Chutes and Ladders suggestion shows a willingness to branch out, to use games that might not at first be obviously mathematical to convey some appropriate mathematical ideas.

Next, the class discussed what made something a game. Ideas that were suggested by the students were the fact that someone wins, that there are points, that people take turns, and finally that there are rules to follow in the course of play. Here, students were able to come up with much of the definition offered by Salen and Zimmerman in *Rules of Play* (2004).

After this brief discussion, students were introduced to three games to be played in classes: *Draw and Compare*, *Division Nim*, and *Set*. In *Draw and Compare,* students have a deck of cards (the numbers on the cards vary depending on the level of the students); two players each draw a card, and the player with the higher card wins both cards. A variation of this game is to have two piles of cards for each player and they each draw two cards, add them, and the player with the larger sum wins the 4 cards. *Division Nim* is a pencil and paper game. Each player picks a number and they add the numbers. This sum becomes the starting number. Player A divides that number by one of its factors and then Player B divides the quotient by one of its factors. The player who loses is the one who divides by a factor and gets a quotient of 1. Finally, *Set* is a very popular card game in which the cards have 4 possible traits, Shape (rhombus, oval, or squiggle), Number (1, 2, or 3), Color (green, purple, or red), and Shading (solid, no shading, or stripes). The goal is to find a set of the 12 cards drawn that have all the same for a trait or all different for a trait.

Before the students played the games, questions inspired by an article, *Let's Do Math: Wanna Play?* from the National Council of Teachers of Mathematics (2005) were posted on the Smartboard, along with the following prompt that invited them to think of themselves as teachers:

Here are some questions to think about as an educator when choosing a game for your kids to play in the classroom:

1. What is the purpose of the game?
2. What is the mathematical content being addressed or encouraged through play?
3. When playing the game, how will students receive feedback while playing and what will they do with this information?
4. What type of play occurs – individual, pairs, teams?
5. Is there a competitive aspect to the game?
6. How will you know if the game is effective?

After playing one of the games in a group and becoming familiar with it, the students presented the games to the rest of the class, with the questions as a frame of reference. Students were already comfortable questioning the quality of the game, and giving suggestions as to how to modify the game for play with a whole class. For example for *Draw and Compare*, one student said that she would model the game first and draw one card, for example, a 7, then ask her class what card they would hope to get to win the round; for *Division Nim*, the students themselves began to critique the game itself, examining the strategies involved in playing. And finally with *Set*, the group that played said the game was too difficult and not fun, but when the instructor of the course demonstrated some questions to get the students thinking about the game they recognized the interesting mathematical learning that could take place.

For homework the students were asked to play *Five-O, Sushi Monster* and *Hungry Fish*, all digital games, and to be prepared to discuss the games in the next class period based on the lens of the questions above and the EduMAp survey questions. The instructor also asked students to think about what kinds of question they would want to ask their own students about the game, after game play was finished. We added this last prompt because we wanted students to think about how they would allow for reflection on the learning taking place in the game, since we had seen the importance of in class reflection and teaching in our *Refraction* results (section 6.1).

In the next class meeting, the instructor recorded the observations from students, as they evaluated the games in terms of the teaching of mathematics. *Hungry Fish* is a game in which players must combine bubbles to add up to certain sums. As game play progresses, more and more bubbles appear, and game play gets more difficult. In addition, there are harder levels, which involve negative numbers. See fig. 3.

Figure 3. Hungry Fish

Hungry Fish has a random component but also more bubbles gives more options for sums

Hungry Fish feels rushed – but can slow it down for smaller numbers

Question for post-game play: "How many different ways do you remember making a sum of 6 or a difference of ______?" and have students list the ways.

Figure 4. Student comments about *Hungry Fish*

Most students could not initially see how to incorporate *Hungry Fish* into the classroom, unless they were to simply allow the students to play on their own. Students liked the random component of *Hungry Fish*, but said it felt rushed, and that the increase in bubbles gave so many more options for sums. One student commented that it was too bad, from a teaching standpoint, that you could not pause the screen to see what combinations the kids could make. Then one student came up with the idea to ask this sort of question after game play (see fig. 4).

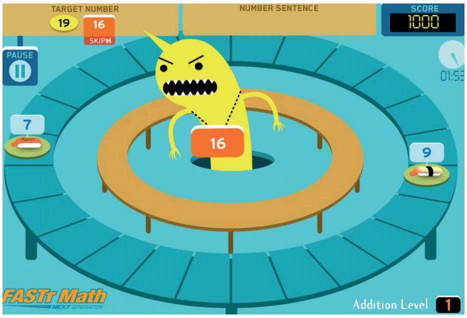

Figure 5. Sushi Monster

Fun
Lots of fun
Nice paced
Can become challenging
The stars enable the teacher to keep track of student progress if they use the same ipad
The students need time to think about the combinations that will make the sums and products
I like that if they make a mistake, it doesn't give the answer and you can pause it and discuss
You can play this with more than one player even though it seems like it is a one player game
Question for post-game play:
"Why did you choose those two factors to make 900 instead of ____?"

Figure 6. Comments about Sushi Monster

In *Sushi Monster*, the goal is to give the correct sushi factors to the monster. Some strategy is involved in picking which factors to give to the monster. As game play progresses, there are more factors to choose from (see fig. 5). There are also levels for addition. Students enjoyed *Sushi Monster* a great deal, many commenting how much fun it was (See fig. 6).

They commented that players needed to think about combinations, and that game play could become challenging. One student pointed out that if a player made a mistake, game play could be paused to allow a student to discuss the problem.

Students contended that both *Sushi Monster* and *Hungry Fish* were fast-paced, which would make deep thinking not possible. However, after some conversation, students began to recognize that if the game did not meet some of the criteria they needed for their classroom, they could modify it. This could be done either with adjustments during game play or in reflecting after it. For example, one student demonstrated how *Sushi Monster* could be played with four students. Another came up with an excellent question to ask after the game, to see what kinds of strategies students were using to pick their factors (see fig. 7).

The game *Five-O* is a crossword-type game, like *Scrabble*, but with numbers instead of letters. Players can compete against the computer or against another person. Many students liked the option to use the feature of pass and play (see fig. 7) but complained that it was a slow game. There were no suggestions for post-game discussion questions, perhaps because in this game the mathematics was so obvious and transparent.

All in all, the students engaged in an intense, productive discussion. Students were beginning to see that games could be more than just time fillers or "fun." Games could be incorporated into classroom learning to encourage thoughtful mathematical exploration and growth.

7. Conclusion

Games are not new, nor is using games to teach. But digital games have opened up whole new ways of teaching with games, because of their ability to give immediate feedback and adapt to a player's responses. The literature and our own experience show that games have a great potential to help students learn math, if used well. With the topic of fractions, an area that often frightens our pre-service teachers, our results show average gains between pre- and post-test with game play alone (no teaching of the material) of 5%. We found even larger gains of over 15% from pre- to post-test when students had game play accompanied by class instruction and reflection. Thus our goal, to teach our students essential mathematics and help them understand it more deeply, was better achieved through the integration of game play and instruction.

We have also found that our survey tool, EduMAp, is an excellent springboard with which students can change how they think about games in the classroom over the course of only a few lessons. Through EduMAp, students have a framework to think about how learning can occur through the use of a digital game, and to think critically about games and pedagogy. Students *experience* how learning can occur through a game while understanding the advantages of game-based learning. When they become teachers, they will be more likely to choose games carefully, with pedagogical goals in mind, rather than merely choosing a game because it seems fun. They will also be able to incorporate games into their own teaching using best practices, like allowing for classroom reflection on the concepts in the game.

EduMap was designed for mathematics apps, but can be adapted to critique apps in other disciplines as well. We welcome other education faculty and teachers to use and change the tool for their own critical analysis of digital games.

8. Future Research Directions

Some further questions arise from our exploration of digital games for math teachers: Are there games where reflection and teaching is unnecessary, because it is contained within the game? Do students who play collaboratively achieve better results? What kinds of games and game play can allow for higher-order thinking?

In our own research, we hope to use EduMap in other ways, for example, as a survey tool to send to teachers to help us create a database of games that can be used in the classroom. This is necessary because with so many digital games out there, sorting through them to find good teaching games becomes more and more difficult.

Additionally, we encourage future critical analysis of digital games for classroom use in the same way teachers would critique a written curriculum. As many have pointed out, there is great potential here – but we add: *provided it is done right*.

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