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# Are You Ready to Teach Secondary Mathematics in the 21st Century? A Study of Preservice Teachers' Digital Game Design Experience

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## Abstract

*This research study examines preservice teachers' experiences of learning through game design. In particular, we investigate how their perceptions of digital games have evolved through the process of designing and building their own educational games. We are also concerned with the knowledge and reasoning skills that preservice teachers incorporate into their games. Further, we investigate the 21st century skills involved in the game design and implementation process. In this case study, the participants are first-year students at a university in Western Canada enrolled in a secondary mathematics methods course. A total of 21 preservice teachers (10 males and 11 females) in the class participated, ranging from ages 20 to 45 years old. We collected three sets of data: open-ended pre- and post-surveys, games created by preservice teachers, and follow-up interviews with selected participants. The analysis of the data shows that the game-building experience impacted preservice teachers' perceptions related to challenges, problems solving, and attitudes toward gaming and design. Further, their games demonstrated these preservice teachers' fair understanding of pedagogical and cognitive components. (Keywords: digital game-based learning, enactivism, secondary mathematics, preservice teachers, learning by game design and building)*

Technology has had a drastic impact on society in the last few decades. From the prevalence of digital social networks to the ubiquitous cell phone, how we interact as citizens and how the global economy operates has changed. Citizens of this new world require a different set of skills to be productive and active members of society (Jenkins et al., 2006). As a result, educators are being called upon to help students develop 21st century skills. These 21st century skills include learning and innovation skills; information, media, and technology skills; and life and career skills (Partnership for 21st Century Skills, 2004).

How do educators prepare children for this new age? Digital games (hereafter games) are generating increasing interest (Gee, 2008a). This is not surprising, considering 97% of teens aged 12–17 play computer, Web, portable, or console games (Lenhart et al., 2008). In particular, learning as digital game design and building is proposed to be an effective approach (Gee, 2008a, 2008b; Kafai et al., 2008). Because students are already interested in games, educators can harness this to exercise 21st century skills in their classrooms by having students design, develop, and build their own digital games. Game design can be used specifically in mathematics education, as it promotes creative thinking and problem-solving skills that can be transferred beyond programming to the classroom (Li, 2010).

Helping students acquire 21st century skills through digital game building and design demands teachers' deep understanding of the related technology and the appropriate pedagogy. Immersing preservice teachers in the experience of designing and building their own games provides an effective opportunity to develop such technological and pedagogical expertise (King, 2011). An opportune time to do this is during teacher training. Game design and building may help preservice teachers develop appropriate attitudes, pedagogy, and technical skills related to gaming and the role of gaming in the classroom. Further, the process can provide preservice teachers the opportunity to experience and test the pedagogical and technical strategies to promote learning of 21st century skills.

In this report we examine preservice teachers' experiences of learning through game design. In particular, we investigate how their perceptions of digital games have evolved through the process of designing and building their own educational games. We are also concerned with the knowledge and reasoning skills that preservice teachers (hereafter teachers) incorporate into their games. Further, we investigate the 21st century skills involved in the game design and implementation process.

## Theoretical Framework

This paper is grounded in the theory of "enactivism" (Li et al., 2010) as it applies to educational technology. The theory of enactivism has two major premises. The first premise is that the mind, body, and world are inseparable (Fenwick, 2000). Enactivism believes that the personal history of the subject and the setting affect the outcomes of events. That is, the outcome of a specific learning activity is determined by the environment of the activity (time, place, etc.) and by the participant (gender, cultural background, action, etc.) (Li et al., 2010).

The second premise is that learning occurs through feedback within the system (Fenwick, 2000). As such, cognition is a complex process of individuals interacting and affecting each other and their environments (Davis et al., 2008). Enactivism places emphasis on knowledge co-authoring. As researchers (Li et al., 2010) state, "[a]ll living systems have to be involved in cognition, and cognition is active rather than passive" (p. 8).

Enactivism holds different beliefs from both behaviorism and constructivism. Behaviorism and constructivism share similar assumptions, although they appeared to be completely different (Davis & Sumara, 2002). A noticeable shared assumption is that cognition sits inside the individual's body, isolated from the world and other people. Reality (the real world) is separated from the mind, even though the two theories have different views about where it is. Behaviorists assert that reality is external to the knower, is structured, and that the structure can be modeled. The purpose of learning is to mirror this abstract reality and its structure through thinking (Davis & Sumara, 1997). Constructivism, regardless of the version, assumes that reality is formed from the mind of the knower through his/her construction (Dewey, 1933; Vygotsky, 1978). Therefore, both behaviorism and constructivism accepts dualism and interpret cognition in mechanistic ways.

Enactivism, in contrast, rejects dualism that divides self from world, mind from body, or subject from object. Therefore, both behaviorism and constructivism focus on knowledge, whereas enactivism emphasizes knowing. Enactivism rejects the idea that knowledge consists of separate objects different from the world. Rather, "all cognition exists in the interstices of a complex ecology of organism relationality" (Davis & Sumara, 1997, p.110).

In enactivism, thinking and cognition are grounded in action (Holton, 2010). The core characteristics of digital game building are doing and co-authoring, which provide an ideal platform for creating an enactivist world in the context of a participatory culture. In this learning world, the teachers are asked to design and build a digital game targeting a specific mathematics topic. The assumption is that the games they create will embody the cognitive processes used and the processes intended for students to use when playing their games.

## Literature Review

Today, students are plugging into, participating in, and authoring digital content on a daily basis. In the late 20th century, digital games became a significant component of children's culture (Gareau & Guo, 2009). As part of this culture, digital game play now has widespread appeal among children (Li, 2010). Instructional games appeal to students, as they provide a new learning culture that corresponds with students' pre-existing habits and interests (Prensky, 2001).

A participatory culture compels participants to discover new fact-finding, content, and technical skills, which enable them to enhance their new media literacy skills (Jenkins et al., 2006). Burdick and Willis (2010) have posited that "literacy itself is situated, networked, and contingent ... and continually negotiated.... Design thinking ... specifically supports this constant emergence" (p. 3). Seymour Papert studied the link between student learning with technology, specifically a hands-on perspective through student design and construction (Papert, 1998). Since then, the concept of digital learning with technology and games has been explored more in depth (Hsaio, 2007; Kirriemuir & McFarlane, 2004).

Digital game-based learning is a promising area of research and debate, as it promotes contextualized learning, creates and harnesses motivation in learning capacities, and encourages curiosity (Gee, 2008a; Kirriemuir & McFarlane, 2004; Prensky, 2006). There is evidence to show that digital games are effective in promoting learning because students are able to interact with virtual worlds where players solve simulations of real-world problems and in the process learn real-world skills, knowledge, and values (Gee, 2008b). Additionally, game play is valuable in the realm of problem solving and learning because it lowers the emotional stakes of failing. That is, students are able to learn through trial and error and suspend real-world consequences (Jenkins et al., 2006).

Designing and creating in this digital environment are aspects of gaming literacy (Zimmerman, 2007). They are embedded within the social skills necessary to interact within a larger community (Jenkins et al., 2006) and are criteria for the acquisition of 21st century skills. Due to students' ongoing relationship with technology, learning by game building has encouraged researchers to perform empirical studies in the subject areas of mathematics (Kafai & Ching, 1996; Noss & Hoyles, 2006), computer science (Korte et al., 2007), and elementary science topics such as physics (Kafai et al., 1997; Li, 2010). In these studies, researchers analyzed and interpreted students' game-building experiences to find patterns, processes, and connections between building and learning.

Proponents of learning by game building are looking at digital literacy skills fostered in teachers for the purpose of training them to facilitate burgeoning 21st century skills among students (Becker, 2007; Gee, 2008b). Inservice teachers have difficulties with understanding how to use games in their classrooms and have concerns about time and availability of technology (Ertzberger, 2009). It has been found that teachers require a connection to the curriculum in order to integrate games (Ketelhut & Schifter, 2011). A proactive method proposed to keep up with the technological skills of students is to provide teacher training in technology and the use of digital games in the classroom (Becker, 2007; Tiong & Yong, 2008).

A study by Kafai and colleagues (1998) explored preservice teachers' experiences of designing games for mathematics learning. They found that the game design activities transformed these preservice teachers from extrinsic game designers (i.e., viewed game idea and math content as separate) to intrinsic game designers (i.e., viewed game idea and math content as integrated). Further, these teachers' understanding of students' thinking provided the foundations for their game design. During the game design process, these teachers played both the designer and player roles in an ongoing way. That is, they considered designing and playing concurrently.

Attitudes toward technology predict how one will behave with technology. Specifically, a teacher's personal experience with technology may not be sufficient to provide the confidence needed for him or her to design lessons that incorporate game-based technology (Sardone & Devlin-Scherer, 2010). Regardless of the educational benefits and prevalence of digital games within student culture, the majority of teachers do not see the immediate value of educational online gaming, gaming communities, or games as a communication tool, but rather see games as rewards. This perception is largely informed by prior experience with games (Schrader et al., 2006).

Despite perceptions of games and game use, teachers are open to new applications of technology and consider games to be important educational tools (Schrader et al., 2006). However, many are not fully aware of the pedagogical uses and benefits of digital games. To combat this, preservice education should incorporate opportunities to experience and reflect upon game use (Schrader et al., 2006; Wright, 2009). Further, when teachers were immersed in a 21st century learning environment, they developed new perspectives regarding the use of games for instruction; certain games could be used to teach content and have students develop 21st century skills (Sardone & Devlin-Scherer, 2010).

Earlier research had also explored teacher development of software, although not directly connecting to game design. In the early 1980s, a focus of educational computing was on teaching teachers to program so that they could create their own software. For example, Oates (1986) reported several different projects where professors developed their own programs for instructional purposes. The projects were conducted in the University of Illinois, University of Oklahoma, Pennsylvania State University, and the City University of New York, respectively. Other studies explored how K–12 teachers could learn programming to improve their students' learning of various subjects, such as English and mathematics (Jackson, 1983; Kagan, 1989). This line of research, however, was questioned and criticized because teachers had neither the skill nor the time to make effective software (Bracey, 1986; Crull, 1987).

Although research in the area of learning through game building is in its early stages, majority of the research has focused either on students or inservice teachers (Gee, 2008b; Kafai, 2006; Kafai et al., 2008). There has been very little done in the area of preservice teachers. Research, thus far, involving preservice teachers has been mainly from the viewpoint of game play—that is, how to incorporate premade digital games into lessons and how game play embodies 21st century skills.

Further, some research has been done in the area of preservice teachers' perceptions of digital games (Sardone & Devlin-Scherer, 2010; Schrader et al., 2006). Limited research investigates the process of preservice teachers designing and building their own games. This study intends to bridge this gap by investigating the experiences of preservice teachers as they designed and built their own digital games. It is important to realize that this line of inquiry is not following the failed design strategy of the 1980s.

## Research Questions

The following questions guided our research investigation:

- How did designing and building a game affect teacher perceptions about digital game building, if at all?
- When teachers were designing games, what pedagogical areas and cognitive skills did they incorporate into their games?
- What kinds of 21st century skills were demonstrated in the teachers' game design and building experience?

In this paper, we used the 21st century skills defined by the Partnership for 21st Century Skills (2004). Such skills include creativity, critical thinking, problem solving, communication and collaboration, information literacy, media literacy and information, communications and technology literacy, flexibility, adaptability, initiative, self-direction, social and cross-cultural skills, productivity, accountability, leadership, and responsibility.

## Methods

Adapting a case-study approach, this study investigated preservice teachers' perceptions of digital games and their experiences designing and building an educational digital game. The case study fits well with our enactivist viewpoint because both share the goals "to place the researcher within the study so as to avoid objectification and to conduct research that is transformative" (Creswell, 1998, p. 83).

### Participants

The participants of this study were first-year students at a university in western Canada enrolled in a secondary mathematics methods course as part of their after-degree bachelors of education program. A total of 21 teachers (10 males and 11 females) in the class participated. Their ages ranged from 20 to 45 years old. Two of the researchers also participated in the study.

The course focused on promoting understanding of mathematics education in the context of a learner-focused, inquiry-based, and field-oriented platform. One project was for teachers to work individually or in small groups to design and build a digital game that focused on algebra.

### Data and Instruments

Three sets of data were collected: open-ended pre- and post-surveys, games created, and follow-up interviews with selected participants. We

**Table 1.** Pre-Survey Questions

| The first survey was given in the first week of class. The questions were as follows: |
|---|
| 1. What do you think about designing/building your own games for students (e.g., benefit, disadvantage)? |
| 2. What do you think about kids creating their own education games for their learning (usually described as learning through designing)? Why? |
| 3. In what ways can you use the 'learning as game-designing' in your classrooms (e.g., elementary music class, adult training program)? Please describe specifics (e.g. who, what, when, how). |
| 4. When designing your own games for students, what are some challenges you would expect? |

**Table 2.** Post-Survey Questions

| The second survey was given at the end of the semester after students had finished their digital games. The questions were as follows: |
|---|
| 1. What do you think about the experience of designing your own games (including paper prototyping and digital games) for students? |
| 2. What are things you've learned/benefit through this game-designing/building experience? Give examples/scenarios to explain your points. |
| 3. What are some challenges you find in designing your own games (including paper prototyping and digital games) for students? |
| 4. Do you plan to use the game you designed in your class? Why or why not? |
| 5. What do you think about kids creating their own education games for their learning? Why? |

administered two surveys, a pre-survey and a post-survey, to examine teachers' perceptions about digital games (see Table 1 and Table 2). We administered the pre-survey during the first week and the post-survey at the end of the semester.

The second set of data consisted of an evaluation of all participants' created games using the pedagogical rubric and the cognitive rubric we developed. The pedagogical rubric focused on the educational aspects of the games, including three categories: knowledge, game play, and playability. The iterative development process started with a discussion among all the researchers about the curriculum standards (e.g., NCTM Standards [2000]) and the critical pedagogical understanding required for mathematics teachers. The initial discussions resulted in the identification and definition of the following five categories: problem solving, representation, active learning, exploration and reasoning, and connections. Each researcher independently evaluated three representative games first using the rubric, and then all researchers worked together to discuss the results, paying particular attention to disagreements. Such discussions led to the inclusion of critical components, the clarification of definitions, and the modification of the ranking system. For example, we realized that games could be unfairly evaluated because of poor game design. We added engagement/motivation, participation, and user friendly and ease of play so as not to punish limited technical skills in the pedagogical areas. We developed a final version of the pedagogical rubric after many rounds of testing and fine-tuning each category. Each researcher then independently evaluated all the games first, and then the whole team discussed them until reaching a consensus. See Appendix A (pp. 333–335) for details.

The cognitive rubric, adapted from the revised Bloom's Taxonomy (Anderson & Krathwohl, 2001), evaluates the depth of thinking skills that are required in playing the game. The development of this rubric took a similar iterative process. For this rubric (see Appendix B, pp. 336–337), the assumption was that the cognitive skills were nested within each other, meaning that if a higher-order thinking skill was used, then the lower-order cognitive skills were implied. For example, applying the cognitive skill of analyzing indicated the use of all the cognitive skills below it (e.g., remember, understand, apply).

The third set of data consisted of the follow-up interviews focusing on the 21st century skills with participants 6 weeks after the course finished. We invited everyone for a follow-up interview and interviewed six teachers on a volunteer basis. We showed these teachers the Partnership of the 21st Century (2004) framework and then asked them to identify the skills they used and provide examples.

We recognized the subjective nature of some subscales, especially engagement/motivation. To establish fidelity, we provided consistent training to the evaluators. We also tested inter-rater reliability. If the inter-rater reliability coefficient was lower than .78, another rater was added to evaluate the game until all four researchers assessed the game. If at this point the agreement rate was still below .78, we had a detailed discussion until we reached a consensus. In addition, as two researchers served the dual role of teacher and researcher, we made sure that they did not evaluate their own games.

### Instructional Process

In this study, teachers were engaged in game design activities. The process started with an introduction of various games during a 2-hour session in which teachers played and evaluated free online games, such as Crayon Physics (http://www.crayonphysics.com). After an hour of play, each worked in a small group to create a lesson plan. The requirement was that the lesson had to use one of the games to teach an algebraic concept. As many teachers were nongamers, such activities enabled them to become familiar with this media. For teachers who were gamers, this exercise gave them an opportunity to re-examine digital games through the eyes of teachers, focusing on educational value rather than just the entertainment value of the games.

A few weeks later, the teachers had another class (3 hours) focusing on game design and paper prototyping. At the beginning, teachers were asked to adapt their favorite movies and transform the movies into board games. In small groups, teachers came up with their game designs, paper prototyped their ideas, and then play-tested each other's games. During this session, they did not use computers. While play-testing a game, everyone in the class was engaged either as an observer or as a player. The designers were asked to refrain from talking or showing and to rather simply observe what players were doing. The instructor gave verbal feedback after each game was tested.


*Shellshocked 2* — *Equalia* — *Fraction Mahjong* — *The Multiplying Game*

*Figure 1.* Screenshots of teachers' games.

At the middle of the semester, the teachers began to develop their own game ideas. The instructor introduced the Web app Scratch (http://scratch.mit.edu) in a class and allowed the teachers to play with the software for about 1 hour. The instructor also created an online forum for these teachers to discuss ideas, help others, and share resources. For example, the instructor provided a link introducing another software program, Kudo (http://research.microsoft.com/en-us/projects/kodu/), in this forum and encouraged them to explore. The teachers had the freedom to use any software platform, but Scratch was the only one introduced in a face-to-face class. At the end of the semester, they spent 2 hours showcasing and playing each other's games as a celebration.

During this process, the instructor provided no instruction about how to choose an algebraic topic. They were also not required to research the use of games in teaching mathematics.

## Games Created

A total of 14 games were created: 4 sandbox games, 1 platform game, 1 role-playing game, and 1 arcade game. The majority of the games (10 of the 14) were designed for late elementary or junior high students, while 3 games were for high school students. Table 3 (p. 318) provides a brief summary of the games that the teachers created. We describe four sample games in detail because they were referred to often in the subsequent sections (see Figure 1 for images).

**Table 3.** Summary of Games Created

| Game Name | Audience (grade) | Program | Type of game | Main curriculum topic | Pedagogical score (out of 18) | Cognitive score (out of 6) |
|---|---|---|---|---|---|---|
| 5 points 4 stars | 5 to 9 | SMART Notebook | Not a game | Geometry | 8 | 2 |
| Awesome Adventure | 7 | Little Big Planet 2 | Platform | Fractions, decimals and percent | 10 | 2.4 |
| Call of Math | 7 to 9 | iWeb | Board game | Variety of topics | 11 | 3.2 |
| Castle Quest | 9 | RPG Maker VX | Role playing game | Solving and manipulating algebraic equations and expressions | 4 | 3 |
| Date Game | 9 to 10 | Scratch | Board game | Linear relationship applications | 10 | 2.5 |
| Equalia | 6 to 7 | Kodu | Sandbox | Balancing equations | 6 | 4 |
| Fraction Mahjong | 7 | SMART Notebook | Board game | Equivalent fractions | 7 | 4 |
| Fraction Town | 7 to 9 | Kodu | Sandbox | Fractions | 6 | 2.25 |
| Fraction War | 7 | Scratch | Card game | Fractions | 6 | 2 |
| Kodu's Treasure Hunt | 7 | Kodu | Sandbox | Linear equation applications | 8 | 4 |
| Linus the Lion's Quest for Stars | 10 to 12 | Scratch | Board game | Graphing | 10 | 4 |
| Multiplying Game | 7 | Scratch | Arcade | Multiplying | 3 | 1 |
| Shellshocked 2 | 10 | Kodu | Sandbox | Systems of linear equations | 12 | 6 |
| Who Wants to be a Math Millionaire? | unknown | Scratch | Board game | Linear equation applications | 8 | 1.6 |

**Shellshocked 2.** In this sandbox game, the player decides between two story lines: They can either help Turtle Montana destroy the oil refinery that is making people sick or they can help the Cloud King by rescuing his kidnapped son. Either way, the players have to collect a certain number of fire and water crystals. To do this, they need to spend a certain amount of time in the fire area, where they gain fire crystals but lose water crystals. Alternatively, they could spend a certain amount of time in the water area, where they gain water crystals but lose fire crystals. The amount of time spent in each area is not apparent from the outset and needs to be worked out by setting up and solving linear equations. Players have to work out the problem and the solution on their own.

**Fraction Mahjong.** This is a modified Mahjong game. Instead of finding identical tiles, the players need to find tiles with equivalent fractions. Like Mahjong, the strategy is deciding which tiles to choose, opening up blocked tiles in such a way that all tiles can be removed. Many cognitive processes are used in this strategy, such as planning, hypothesizing, organizing, and testing.

**Equalia.** In this game, grade 6 and 7 players learn about balancing equations by making an equal number of objects on two sides of a fence. Sometimes mathematical objects are missing that need to be added. Sometimes extra objects need to be removed.

**The Multiplying Game.** This remedial multiplication exercise for grade 7 students asks players to multiply single-digit numbers to keep critters away from a breakdancer. The critters are pushed back when the player multiplies correctly; otherwise the critters continue to advance. As the game progresses, the critters advance faster and faster.

### Data Analysis

We answered the first research question by examining teacher responses to two surveys to identify salient themes. We then performed a frequency count for each theme.

We answered the third research question through analysis of the games, classroom observations, and follow-up interviews. The thematic analysis for both research question 1 and 3 adapted a three-step process, starting with open coding (Corbin & Strauss, 1990) of all written work. We worked independently to identify recurring and salient themes during this step. In the second step, we compared these naturally emerging themes with the existing literature of learning-as-game designing. This allowed us to examine the summarized data and create general categories from the full data set. We created a matrix of merged themes to support the overall interpretation of the data.

In the third phase, we conducted a cross-case analysis via matrices and other displays to further condense the data and draw comparisons (Miles & Huberman, 1994). We summarized the coded information about each participant in matrices and then compared them to cluster cases. Grouping the data under different codes allowed us to see different patterns and emergent themes. During this iterative process, we adapted a constant comparative approach (Corbin & Strauss, 1990) to create, refine, and recreate themes and codes (Miles & Huberman, 1994).

We answered the second research question by evaluating the games created based on the pedagogical rubric and the cognitive rubric. We gave each category in the pedagogical rubric a value: 0 for did not meet expectations, 1 for met expectations, and 2 for exceeded expectations. We obtained the total score for the game (out of 18) by summing up the ranks of each category. (See Table 4 and Table 5, p. 320.)

For the cognitive rubric, we rated each problem in the game from 1 to 6, where 1 meant that solving the problem would require minimal cognitive skills and 6 meant that solving the problem would require extensive cognitive skills. We determined the cognitive score for the entire game by finding the average of the cognitive scores for each of the problems. We then analyzed the games by looking at the descriptive statistics of the results. The

**Table 4.** Summary of Pedagogical Rubric (Individual Categories)

| Category | Did Not Meet Expectations | Met Expectations | Exceeded Expectations | Mean | Median | Mode |
|---|---|---|---|---|---|---|
| Problem solving | 7 | 3 | 4 | 0.79 | 0.5 | 0 |
| Representation | 2 | 10 | 2 | 1.00 | 1 | 1 |
| Active learning | 2 | 9 | 3 | 1.07 | 1 | 1 |
| Exploration & Reasoning | 6 | 6 | 2 | 0.71 | 1 | 0 |
| Connections | 9 | 3 | 2 | 0.50 | 0 | 0 |
| Strategy | 7 | 5 | 2 | 0.64 | 0.5 | 0 |
| Engagement/motivation | 0 | 13 | 1 | 1.07 | 1 | 1 |
| Participation | 1 | 10 | 3 | 1.14 | 1 | 1 |
| User friendly & ease of play | 3 | 9 | 2 | 0.93 | 1 | 1 |

*Note.* To create a score for each rubric, a "does not meet expectations" is a 0, a "meets expectations" is a 1, and an "exceed expectations" is a 2. The most a game can get is 18 points.

**Table 5.** Summary of Pedagogical Rubric (Total Scores)

| Statistic | Result |
|---|---|
| Count | 14 |
| Mean | 7.9 |
| Median | 8 |
| Mode | 8 |
| Minimum | 3 |
| Maximum | 11 |

data we obtained from both rubrics were nonordinal. The median was the measure of center that we used for analysis, and we applied no measures of variation. (See Table 6.)

## Results

### Perceptions

How did the game design and building experience affect teachers' perceptions? The analysis of teachers' survey showed that three major themes emerged: challenges, problem solving, and attitudes toward gaming and design.

### Challenges

The first and foremost theme that emerged was challenges in game design and building, indicating that the game design experience changed teachers' perceptions about specific challenges they would face.

Before the teachers began the project, the greatest challenge that 62 percent envisioned was coming up with a game design that would be fun and interesting to play. They were concerned about their ability to create a game that would engage the students while still being educational, as these comments reflect:

**Table 6.** Summary of Cognitive Rubric (Total Scores)

| Statistic | Result |
|---|---|
| Count | 14 |
| Mean | 2.93 |
| Median | 2.45 |
| Mode | 4 |
| Minimum | 1 |
| Maximum | 6 |

> It takes a lot of effort creating a game that is fun, engaging and incorporates learning concepts. (PH, pre-survey)

> [Y]ou can very easily design a game that students find boring, thereby defeating the purpose of using video games in the first place. (DC, pre-survey)

Teachers were also concerned about having enough creativity to come up with an interesting game design. More than one-third of the teachers mentioned this, as exemplified by RK's comment: "Creativity can be a challenge for me. I often find it difficult to come up with a good idea from scratch; I need some outside input to work with" (pre-survey).

Thus, the primary concerns of teachers before they began the project were envisioning the concept behind the digital games and creating a final game that would be fun and interesting for the students to play.

Designing and building their own games changed teachers' perceptions of the challenges they would experience. When asked about the actual challenges they experienced in the post-survey, only 3 of the 21 teachers mentioned making the game fun and interesting, and only one mentioned creativity. The number of teachers concerned with creativity and making a fun and interesting game greatly decreased after the project, suggesting that the expected challenges had been exaggerated.

In the post-survey, a challenge that a majority of the teachers discussed was programming. Many experienced difficulty in translating their design ideas to a game. Some teachers had to completely change their game designs to fit the program they used. For example, participant MG felt "limited by what kind of interface we choose for our game—our ideas can be really great and seem simple, but are hard to put into action" (post-survey). Participant AA stated, "I wanted to make a story-based kind of game, but was too difficult. So I had to change the game ... [it] became a simple question and answer game with scoring points" (post-survey).

Analysis of the games confirmed this challenge. For instance, Shellshocked 2 is a game that teachers DC and JH developed. The initial plan had players answering mathematics questions while venturing through the game space. But they were unable to accomplish that goal. In the final game, players could accidently access a part of the game that is only supposed to be open after players finish a puzzle. Thus, one could complete the whole game without answering any mathematics problem.

### Problem Solving

Teacher perceptions of the importance of problem solving in game design changed through the process of designing their own games. In the pre-survey, the most commonly considered benefit was that the game design experience would push students to gain a deep understanding of the mathematics content in order to design their own games, as reflected in these comments:

> When a kid designs an educational game he must understand the underlying educational concepts associated with the game. (DC, pre-survey)
>
> This 'learning through designing' would benefit the students by prompting them to consider their understanding of mathematics from a different point of view ('how can I use what I have learned? rather than 'here is what I have learned'), and providing them with a unique and engaging opportunity to create meaning truly for themselves. (LW, pre-survey)

Although it is an important skill in mathematics learning, problem solving was mentioned by only 2 out of the 18 teachers as a benefit of learning through game design in the pre-survey. Participant KG stated, "I also think that even the general thinking patterns required to make a game can help the students with their math skills (this would involve counting, patterns possible, time management, etc.)" (pre-survey).

There was a marked increase in the number of teachers who mentioned problem solving as a benefit for students designing their own games in the post-surveys. In fact, close to 40% of the teachers discussed how game design provided opportunities for learners to exercise their problem-solving capabilities, as demonstrated by the following comments:

> Programming and coding also requires students to be effective problem solvers in order to get their games to work the way they want it to. (PH, post-survey)
>
> I think it would be beneficial to have students try to design games because: Their problem-solving skills would be developed, which is incredibly valuable in all areas of school and life in general. (DC, post-survey)

### Pedagogical and Cognitive Skills

What are the pedagogical and cognitive skills involved in teacher designed games? Analysis of data showed that teachers were already meeting expectations for incorporating educational components in their games. Further, a link between a game's score on the pedagogical rubric and on the cognitive rubric was revealed.

**Pedagogical consideration.** For the most part, teacher-designed games were meeting or exceeding expectations in the majority of the educational areas measured by the pedagogical rubric. More than half of the games either met expectations or exceeded expectations for six out of the nine categories. These six categories were: representation, active learning, exploration and reasoning, engagement/motivation, participation, and user friendly and ease of play. Specifically, in 12 of the 14 games, students needed to represent mathematical ideas in a variety of forms and apply different concepts across different mathematical areas. For the categories of problem solving and strategy, half of the games either met expectations or exceeded expectations.

Further, every game met or exceeded the expectation in the category of engagement/motivation. In addition, 13 of the 14 games were designed to encourage the majority of students to play and enjoy the games (participation), and 11 of the games were user friendly. Therefore, we could conclude with confidence that teachers made reasonably enjoyable games.

Connections was the only category that more than half of the games failed. Yet four games focused entirely on applications of mathematical ideas to the real world, therefore making connections their main focus. For example, The Date Game was about either a boy or a girl (the player decides) getting ready for a date by getting his or her hair done, buying a new outfit, and getting a present for the date. Through applications, the game connected solving linear equations to students' lives.

In summary, all but one pedagogical category was significantly addressed by at least half of the games designed by the teachers. Such integration of the important pedagogical knowledge into the games demonstrated that a majority of the teachers had deep understanding of these pedagogical principles.

**Cognitive processes.** We also evaluated the games focusing on the cognitive aspect, which contained six categories in ascending order: remember, understand, apply, analyze, evaluate, and create. The first two categories were considered lower order thinking and the rest considered as higher-order thinking. The vast majority of the games (12 out of 14) required at least the use of understanding, while almost half of the games (6) required at least the use of applying to complete the game. That is, about half of the games embedded higher-order thinking skills.

Most of the games (11) had cognitive scores between 2 and 4 (inclusive), indicating that most games involved understanding, applying, and analyzing. Only one game, Shellshocked 2, went beyond analyzing. Therefore, it appears that teachers were mostly having students use, at most, the skill of analyzing in the problems they had designed for their games.

Having said that, when the teachers actively stepped away from the standard view of how to present mathematical problems (i.e., the worksheet mentality), the types of problems they developed were very rich. Shellshocked 2 and Equalia exemplified the kinds of games created that embraced the environment of a digital game and posed rich problems.

One prevalent theme that arose was that the problems presented in many games were not much different from worksheets. The mathematical questions were add-ons to the games instead of embodiments of the games. For example, Castle Quest was about a young wanderer who needed to free a castle from a curse by finding objects and manipulating algebraic expressions. Although it is a very engaging fantasy game with motivating storylines, the math problems presented were disappointing. The math solution method is known in advance, and the problems do not enable players to develop new mathematical understanding. Further, the questions were not embedded in the storylines, making the math learning superficial.

**Link between pedagogical and cognitive skills.** We identified a link between the pedagogical components and the cognitive processes in the games. That is, a high score of a game on the pedagogical rubric tended to achieve a high score on the cognitive rubric. Half of the games received a total score of at least 8 on the pedagogical rubric, meaning that half of the games were either at least meeting expectations or close to doing so. Additionally, half of the games received a score of at least 2.45 out of 6 on the cognitive rubric, suggesting that at least half of the games were using at least the cognitive skill of understanding.

Comparing the pedagogical rubrics with the cognitive scores, all the games that were above the median total score for the pedagogical rubric also had cognitive scores above the median. All games except one that had pedagogical scores below the median also had cognitive scores below the median. The exception was Fraction Mahjong, which scored high on the cognitive rubric but low on pedagogical rubrics. Of those games that had exactly 8 for their pedagogical scores, two were below the cognitive median and two were above.

At first glance, it seemed obvious that the pedagogy scores and the cognitive scores were connected. Upon further scrutinizing, however, we noted that the two rubrics focused on different components of the game. The pedagogical rubric focused primarily on the mathematical contents posed, whereas the cognitive rubric looked at the problems needed to complete the game as a whole. For example, Fraction Mahjong scored low on the pedagogical rubric because the mathematical problems were not reflecting good mathematical thinking, but the strategy needed to complete the game required higher-order thinking, resulting in a high cognitive score. The link demonstrated that the teachers who were designing good mathematical questions were also having players use higher cognitive skills to complete the game.

## 21st Century Skills

The analysis of the follow-up interviews suggested that the game design process enabled teachers to use all the 21st century skills, and further scrutiny of the games confirmed that they demonstrated all the 21st century skills. First and foremost, teachers exercised creativity and innovation skills in the development of their ideas for the games. Participant RK's statement perfectly demonstrated this: "From nothing I made a game" (follow-up interview).

They constantly exercised critical-thinking and problem-solving skills, most prominently during the process of programming and de-bugging the game, as exemplified by the following comment: "Problem solving was a large component of the design. This was used in figuring out how the programming language worked and the debugging" (CV, follow-up interview).

The teachers practiced communication skills during all phases of the game design and development, especially during the process of creating the game scenarios and rules. For example, Shellshocked 2 and Fraction Town began with clear and concise instructions of what the players needed to do. Teachers needed to carefully consider the best ways to communicate their ideas to the players.

Although not required, almost all the teachers collaborated in one way or another. For those who chose to work in groups, collaboration was an ongoing process, as described in the following comment:

> LW and I worked both collaboratively and parallel on the game. Initially we discussed our game vision and ideas, then we each played with Kodu separately to see what was possible. We reconvened and decided what would work and how we would implement it. We would pass the game back and forth between our computers to each try and problem solve/debug separately and discuss the optimal/most effective solution. (CV, follow-up interview)

Even for those who worked individually, they started their game designs in a small group setting and tested and discussed their prototypes during the class where classmates provided valuable feedback. The teachers often helped each other with programming even if they weren't in the same group. For instance, in one class, teacher MT gave the class an impromptu lesson on Kodu. Many of the teachers stayed past class time to work with others. Needless to say, technology literacy was a significant component in building the digital games. All of the teachers produced built games and demonstrated technological literacy in this regard.

Some skills seemed unnecessary at the beginning, yet the data showed that they were exercised extensively. For example, when teachers had difficulty programming, they researched previously completed games to get help: "I had to go to the Scratch website and find other creations that did what I wanted to do. Then I had to search for the right thing in the code that did what I wanted to do" (RK, follow-up interview).

Here RK was using information literacy skills by finding, assessing, managing, and finally using previously developed Scratch games. Many of the teachers noted in class the use of tutorials and Internet searches as methods for learning how to program in their chosen game interface.

Flexibility and adaptability skills were also very apparent. When teachers could not program what they wanted, they adapted their plan to fit the programming platform they chose. For example, to create Awesome Adventure using Little Big Planet 2 (LBP2), the team's original idea was to have players drop fractions that were written on blocks that they thought were equivalent to each other down a hole. The blocks with the correct answers would fill up the hole bit by bit until the players could cross it. If the answer was wrong, however, the block would fly out of the hole. However, the team could not program this in LBP2, so it decided to modify this idea by using triggers that could be flipped only if the right answer was given. For example, in one problem, the players had to find three fractions that were equivalent to different representations of fractions (decimal, percentage, visual). When all three correct blocks were put in the right space, an "and" switch was triggered, revealing a bumblebee. The player could then ride the bumblebee to the next level. The new design turned out to be more interesting for players, as it is more fun to fly on a bumblebee than just walk over blocks.

All teachers demonstrated media literacy, as they all created media products—their games. Some teachers developed additional media products to promote their games. One example was the movie trailer that the Call of Math team created to accompany and promote their game. Everyone demonstrated the life and career skills, because every team completed their games in an appropriate timeframe, and many worked collaboratively in small-group settings to create their game designs.

Though not a specific skill as outlined by the Partnership for 21st Century Skills, the crucial skill of perseverance is worthy of detailed discussion. For example, the Awesome Adventure team was confronted with a very difficult problem: how to design questions in LBP2 so that players knew when they were right to continue. The team had to learn the various solutions by watching the tutorial videos that LBP2 offered and reading LBP2 level design forums on the Internet to overcome the difficulty of programming and solving problems, demonstrating their determination.

In the follow-up interviews and post-surveys, the theme of perseverance came up often. "I have learned to persevere. I had a lot of difficulty at the beginning, but kept at it and finally got a great product" (EM, post-survey). Programming could be frustrating and difficult, but it was rewarding when a finished game is made, as illustrated by this comment:

> Programming, for me, has this amazing ability to push me to seek solutions. Maybe it's that there is this amazing feedback present where it smacks you in the face: 'This does not work.' So you persevere until you get to that moment of completion. But at that moment of completion, you KNOW that it does what you want, there is this euphoria. (EL, follow-up interview)

The game design and building experience allowed teachers the opportunity to complete a project that required a great deal of determination.

## Discussion

In this study, we sought to understand enactivism by applying the theory to practice and demonstrating a successful implementation of enactivism in a teacher education classroom. By adapting enactivist approaches, we have created a learning world that incorporates complex real-world problems while giving learners great freedom of exploration.

### Key Findings

Among various positive outcomes, the most significant finding is that the enactivist learning world created rich opportunities for teachers to develop into problem solvers through perseverance. In typical classrooms, including preservice classrooms, students (in this case, preservice teachers) do not often show perseverance when solving a problem. Instead, they often give up relatively easily and wait for the correct answers, for various reasons. If one knows that the teacher will provide the answer at some point, she or he has no incentive to continue to struggle with the problem. Further, much schoolwork, such as assignments, is presented with clearly laid-out steps. There is no need for the student to understand the steps or how to solve the problem, but simply to follow the step-by-step procedure. All these push students, including preservice teachers, into becoming impatient problem solvers who lack initiative, perseverance, and retention and have an aversion to word problems (Meyer, 2010).

In this enactivist world, we have intentionally provided rich opportunities for the teachers to explore freely, engendering self-initiative and eliminating the crutches that give them excuses to give up. Digital game design, with no expert programmer or designer available, is a tool that embodies the skill of persistence. In this world, teachers have designed games in different programs that the instructor is not an expert in. Thus, one of the biggest crutches in the classroom is eliminated: The instructor sometimes does not know the answer. No longer can students rely on someone else to provide answers. In addition, self-initiative is encompassed in the process. When teachers overcome the problems, the result is a functional game that they can share with others with excitement and pride.

An important implication is that instructors should be comfortable not being an expert in every aspect of their instruction and to provide learners freedom to discover. In this study, allowing the teachers to struggle through their difficulties resulted in the discovery of their creativity and confidence.

Teachers in this study demonstrate all the 21$^{st}$ century skills through the game design and building experience. This is consistent with the previous conclusions of Sardone and Devlin-Scherer (2010), who demonstrated that the use of digital games in the classroom allows teachers to use 21$^{st}$ century skills, particularly in the areas of learning and innovation.

Teachers learning in such an enactivist world changed their perceptions. The teachers did not recognize the creative skills that they possessed at the outset. The creative process of designing games forced them to move out of their comfort zones, demonstrating that they were capable of making fun and interesting games. Such realization of their creativity may consequently help teachers foster their own students' creative thinking.

## Implications for Practice

Learning in such an enactivist world has impacted teachers positively in various ways, from changed perception to the demonstrated 21st century skills. From the enactivist perspective, it would be difficult to teach someone else a skill that was not currently embodied or experienced by the teacher. As such, providing teachers with experiences of exercising 21st century skills may help them better facilitate these skills in their future classrooms.

In this enactivist learning world, teachers are the agents of their own learning: They determine their own role in the process and choose their own way of interacting with the software, colleagues, and players. One of the few requirements is the games' focus on algebra. Choosing algebra is deliberate because its abstract nature often challenges teachers to relate it to students, which often makes it a boring topic to learn and difficult to teach. Focusing on algebra, teachers were forced to be creative in both the delivery format (digital game) and the problems. By experiencing this challenge, teachers became better equipped to challenge students' preconceived notions of algebra.

As mentioned earlier in this paper, in the 1980s, when the software market was not yet developed, many studies explored letting teachers create their own software. This effort failed because teachers lacked the needed skills and the time to develop effective software. Our study is a significant departure from that failed line of research for several reasons. First, the technology has advanced drastically in the last two decades. Web 2.0 tools provide user-friendly and easy-access means for anyone to create, share, and communicate beyond the walls of the classroom. Second, unlike teachers three decades ago, the current generation of preservice teachers have grown up in a digital world. This means that they are already familiar with social media, games, and many other tools. Finally, and most important, our focus is not on developing effective software but rather on the teacher's experience of pedagogical and technical skills to promote 21st century skills. Pedagogical and content learning is interwoven organically with game design. This shift of focus suggests that teachers spend time on pedagogical learning instead of polishing the quality of the game.

This study shows that teachers require support to make the leap from worksheets to richer problems and problems that connect to the real world. Having teachers develop their own games is a positive move. Additional guidance in developing rich problems and using these problems in the classroom would further benefit teachers in this area.

As discussed above, the teachers were immersed in game design and building—an inherently messy process. This process helped and even forced them to take initiatives, to persevere, and to be creative in finding workable solutions. That said, several teachers did become frustrated when they had trouble programming their games. Two important strategies proved to be effective. First, collaboration in various ways was highly recommended. Teachers were allowed to work in small groups and were encouraged to help each other within their own groups and across teams. Second, upon observing the negative feeling among a few teachers, the instructor designed a class activity exploring the pros and cons of this project. Interweaving pedagogical discussion with game design, the instructor asked the teachers to generate their own lists of advantages and disadvantages of game design in mathematics learning. Because the ideas emerged from their own conversations rather than being imposed on them, the teachers had a deeper understanding of the value of the project and became more receptive to continuing the work.

The final celebration showcasing their games was the culminating point, when everyone in the class was so excited and felt proud of him/herself. "We are so glad that we persevered!" was a reflective comment made by many of these teachers.

## Limitations and Recommendations for Further Research

A limitation of the study is that the sample size for the follow-up interviews was small, with only six teachers. Future study can include how the process of designing and building affects preservice teachers' teaching style when they become inservice teachers. Researchers may also want to investigate whether the concept of learning by doing permeates into other areas. That is, do they have students learn by doing in areas other than digital games?

Another limitation is that some subscales are based on a subjective experience. One example is the engagement/motivation subscale. One may find a game interesting and engaging, whereas another could find it boring and dull. Future research is recommended to have the games' target audiences (e.g., middle/high school students) evaluate games, which may provide a more definitive result.

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## References

Anderson, L. W., & Krathwohl, D. R. (2001). A taxonomy for learning, teaching, and assessing: *A revision of Bloom's Taxonomy of Educational Objectives.* New York: Longman.

Becker, K. (2007). Digital game-based learning once removed: Teaching teachers. *British Journal of Educational Technology, 38*(3), 478–488.

Bracey, G. (1986). Deprogramming CAI and computer literacy. *Phi Delta Kappan, 68*(1), 74–75.

Burdick, A., & Willis, H. (2010). *Digital learning, digital scholarship, and design thinking.* Paper presented at the Design Thinking Research Symposium 8, Sydney, Australia.

Corbin, J., & Strauss, A. (1990). Grounded theory research: Procedures, canons, and evaluative criteria. *Qualitative Sociology, 13,* 3–21.

Crull, S. (1987). Computer assisted teaching. *Teaching Sociology, 15*, 82–83.

Davis, B., & Sumara, D. (1997). Cognition, complexity and teacher education. *Harvard Educational Review, 67*(1), 105–125.

Davis, B., & Sumara, D. (2002). Constructivist discourses and the field of education: Problems and possibilities. *Educational Theory, 52*(4), 409–428.

Davis, B., Sumara, D., & Luce-Kapler, R. (2008). *Engaging minds: Changing teaching in complex times* (2nd ed.). Mahwah, NJ: Lawren Erlbaum Associates.

Dewey, J. (1933). *How we think.* Boston: Heath.

Ertzberger, J. (2009). *An exploration of factors affecting teachers' use of video games as instructional tools* (EdD dissertation). Pepperdine University, Malibu, California.

Fenwick, T. (2000). Expanding conceptions of experiential learning: A review of five contemporary perspectives. *Adult Education Quarterly, 50*(4), 243–272.

Gareau, S., & Guo, R. (2009). "All work and no play" reconsidered: The use of games to promote motivation and engagement in instruction. *International Journal for the Scholarship of Teaching and Learning, 3*(1), 1–12.

Gee, J. (2008a). Learning and games. In K. Salen (Ed.), *The ecology of games: Connecting youth, games, and learning* (pp. 21–40). Cambridge, MA: he MIT Press.

Gee, J. (2008b). *What video games have to teach us about learning and literacy* (2nd ed.): Palgrave Macmillan.

Holton, D. (2010). *Embodied cognition and enactivsm: Implications for constructivitsm and conceptual change.* Paper presented at the Annual meeting of AERA, Denver.

Hsaio, H. (2007). *A brief review of digital games and learning.* Paper presented at the First IEEE International Workshop on Digital Game and Intelligent Toy Enhanced Learning (DIGITEL'07), Jhongli, Taiwan.

Jackson, S. (1983). *Getting started: The foreign language teacher and computer-assisted instruction.* Paper presented at the Southern Conference on Language Teaching, Valdosta, GA.

Jenkins, H., Clinton, K., Purushotma, R., Robison, A., & Weigel, M. (2006). *Confronting the challenges of participatory culture: Media education for the 21st century* (pp. 66). Washington, DC: The John D. and Catherine MacArthur Foundation.

Kafai, Y. (2006). Playing and making games for learning: Instructionist and constructionist perspectives for game studies. *Games and Culture, 1*(1), 36–40.

Kafai, Y., & Ching, C. (1996). *Meaningful contexts for mathematical learning: the potential of game making activities.* Paper presented at the International Conference on Learning Sciences Bloomington, IN.

Kafai, Y., Ching, C., & Marshall, S. (1997). Children as designers of educational multimedia software. *Computers and Education, 29*, 117–126.

Kafai, Y. B., Franke, M. L., Shih, J. C., & Ching, C. C. (1998). Game design as an interactive learning environment for fostering students' and teachers' mathematical inquiry. *International Journal of Computers for Mathematical Learning, 3*(2), 149-184

Kafai, Y., Heeter, C., Denner, J., & Sun, J. (2008). Pink, purple, casual, or mainstream games: Moving beyond the gender divide. In Y. Kafai, C. Heeter, J. Denner & J. Sun (Eds.), *Beyond Barbie and Mortal Kombat: New perspectives on gender and gaming* (pp. xi-xxv). Cambridge, MA: Massachusetts Institute of Technology (MIT) Press.

Kagan, D. (1989). Research on computer programming as a cognitive activity: Implications for teh study of classroom teaching. *Journal of Education for Teaching, 15*(3), 177–189.

Ketelhut, D., & Schifter, C. (2011). Teachers and game-based learning: Improving understanding of how to increase efficacy of adoption. *Computers & Education, 56*(2), 539–546.

King, K. D. (2011). Teachers' use of standards-based instructional materials: Partnering to research urban mathematics education reform. In W. F. Tate, K. D. King, & C. R. Anderson (Eds.), *Disrupting tradition: Pathways to research and practice in mathematics education.* Reston, VA: National Council of Teachers of Mathematics. .

Kirriemuir, J., & McFarlane, A. (2004). *Literature review in games and learning.* Bristol: Nesta Futurelab.

Korte, L., Anderson, S., Pain, J., & Good, H. (2007). *Learning by game-building: A novel approach to theoretical computer science education.* Paper presented at the annual SIGCSE conference: Innovation and Technology in Computer Science Education, Dundee, Scotland.

Lenhart, A., Kahne, J., Middaugh, E., Macgill, A., Evans, C., & Vitak, J. (2008). *Teens, video games, and civics* (Vol. 2008). Washington, DC: PEW Internet & American Life Project.

Li, Q. (2010). Digital game building: Learning in a participatory culture. *Educational Research, 52*(4), 427–443.

Li, Q., Clark, B., & Winchester, I. (2010). Instructional design and technology grounded in enactivism: A paradigm shift? *British Journal of Educational Technology, 41*(3), 403–419.

Meyer, D. (Producer). (2010). *Math needs a makeover.* [Video File] Retrieved from http://www.ted.com/talks/dan_meyer_math_curriculum_makeover.html

Miles, M., & Huberman, A. (1994). *An expanded sourcebook: Qualitative data analysis* (2nd ed.). Thousand Oaks, CA.: Sage Publications.

National Council of Teachers of Mathematics [NCTM]. (2000). *Principles and standards for school mathematics.* Reston, VA: Author.

Noss, R., & Hoyles, C. (2006). Exploring mathematics through construction and collaboration. In R. K. Sawyer (Ed.), *Cambridge handbook of the learning sciences* (pp. 389–408). New York: Cambridge University Press.

Oats, W. (1986). Advertising profs develop software for media course. *Journalism Educator, Summer,* 51–54.

Papert, S. (1998). Does easy do it? Children, games, and learning. *Game Developer, 6,* 87–88.

Partnership for 21st Century Skills. (2004). *A framework for 21st century learning.* Retrieved June 28, 2012, from http://www.p21.org

Prensky, M. (2001). Digital natives, digital immigrants. *On the Horizon, 9*(5), 1–4.

Prensky, M. (2006). *"Don't bother me mom—I'm learning."* St. Paul, MN: Paragon House.

Sardone, N., & Devlin-Scherer, R. (2010). Teacher candidate responses to digital games: 21st century skills development. *Journal of Research on Technology in Education, 42*(4), 409–425.

Schrader, P. G., Zheng, D., & Young, M. (2006). Teachers' perceptions of video games: MMOGs and the future of preservice teacher education. *Innovate: Journal of Online Education, 2*(3), 1–10.

Tiong, K., & Yong, S. (2008). *Learning through computer game design: Possible success (or failure) factors.* Paper presented at the International Conference on Computers in Education, Taipei, Taiwan.

Vygotsky, L. (1978). *Mind in society: The development of higher psychological processes.* Cambridge, MA: Harvard University Press.

Wright, P. (2009). Trainee teachers' e-learning experiences of computer play. *Innovate: Journal of Online Education, 5*(4), 1–7.

Zimmerman, E. (2007). Gaming literacy. *Harvard Interactive Media Review, 1*(1), 30–33.

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# Appendix A

## Pedagogical Rubric

| Category | Minimal Representation | Fair Representation | Extensive Representation |
|---|---|---|---|
| Problem solving | No events or one small event that showed problem solving. | One substantial event, or two or three distinct small events that showed problem solving. | More than one substantial event, or more than three distinct small events that showed problem solving. |
| Active learning | No events or one small event that allowed for active learning. | One substantial event, or two or three distinct small events that allowed for active learning. | More than one substantial event, or more than three distinct small events that allowed for active learning. |
| Exploration and Reasoning | No events that allowed for exploration and reasoning. | One substantial event, or two or three distinct small events that allowed for exploration and reasoning | More than one substantial event, or more than three distinct small events that allowed for exploration and reasoning. |
| Connections | No events or one small event that showed connections. | One substantial event, or two or three distinct small events that showed connections. | More than one substantial event, or more than three distinct small events that showed connections. |
| Strategy | No events or one small event that showed strategy. | One substantial event, or two or three distinct small events that showed strategy. | More than one substantial event, or more than three distinct small events that showed strategy. |
| Participation | Does not encourage most players to participate. | Encourages most players to participate. | Encourages all players to participate. |
| Engagement/ Motivation | The game is not interesting or fun to play. | The game is interesting and fun to play. | The game is really interesting and really fun to play. |
| User Friendly and Ease of Play | Confusing or unclear objectives or instructions. Many elements that caused major frustration in play and may cause player to stop playing. | Clear objectives and instructions of the game. A few elements that cause minor frustration in play. | Very clear objectives and instructions of the game. No elements that cause frustration. |
| Collaborations | The game doesn't allow any form of collaborations with other players or with other objects in the game. | The game allows for some collaboration. | The game encourages several collaborations, whether it is with non-player characters or with other gamers. |
| Scaffolding | No scaffolding occurs within the game. There is no support for progression of knowledge or concepts in the game. | The game creates an adequate platform for scaffolding through tutorials or guides. | The game goes above and beyond in setting up stages and levels that progress the concepts conveyed in an increasingly challenging way. |
| Assessment | The game has no characteristics that help the gamer to assess their level or situation within the game. Gamer may feel lost when trying to understand his/her abilities and/or achievement in the game. | The game provides tools (e.g. hit points, level ups, gauges/ meters, visual maps, messages and alerts) to adequately assess the gamers progression through the game. | The game is set up in a way that makes the gamer feel as though he/she knows how his/ her character is doing, what levels have been achieved or need to be, and is able to make conjectures on the gameplay because of it. |

### Definitions of Categories

This rubric is designed to see if a game was created that promotes good teaching and good learning. That is, the game isn't just a digital worksheet. Instead the game promotes inquiry, critical thinking, and exploration. In no way would we suggest that these categories are mutually exclusive.

**Problem solving.** Problem solving "means engaging in a task for which the solution method is not known in advance. In order to find a solution, students must draw on their knowledge, and through this process, they will often develop new mathematical understanding" (NCTM, p. 52). The game should encourage students to "build new mathematical knowledge through problem solving; solve problems that arise in mathematics and in other contexts; apply and adapt a variety of appropriate strategies to solve problems" (p. 52).

**Representation.** Representation refers "both to process and to product—in other words, to the act of capturing a mathematical concept or relationship in some form and to the form itself" (NCTM, p. 67). The game should encourage players to "create and use representations to organize, record, and communicate mathematical ideas; select, apply, and translate among mathematical representations to solve problems; use representations to model and interpret physical, social, and mathematical phenomena" (NCTM, p. 67). (Note: If the game gives players an act of representation that is repeated throughout the game, then this is one substantial event. For example, if students are expected to convert fractions to another form for the whole game, that is one substantial event for representation.)

**Active learning.** Here we are looking for components of the game that make a student think about what they are doing. As a negative definition, inactive learning occurs when a student is just given a simple question and is asked to answer it. Instead active learning occurs when students develop their own questions and/or are presented with a complex enough question that multiple steps are required to answer it (and these steps are not laid out for the student). Players may have to think outside of the game. The mathematics is not necessarily explicit.

**Exploration and reasoning.** Rich problems allow for students to explore and discover the solution rather than solving it by straightforward computations. They allow for students to "make and investigate mathematical conjectures" (NCTM, p. 56) and to look for and identify patterns and structures. Here we are looking for problems that allow students to further their understanding of the topic by delving into the problem and justifying their solution.

**Connections.** Here we are looking for components of the game that relate the material to different areas in mathematics (e.g., if the game is specifically examining fractions, then if the game also examines linear functions, this would be an example of a connection to a different area in mathematics), different subject areas (e.g., the game includes components related to physics or biology), or real-world experiences that the students whom the game is targeted at would be knowledgeable of and experience in their own lives (e.g., relating percent to tax).

**Strategy**. Within the game, do players have to strategize to arrive at the end? That is, there are elements of the game that require the player to make a plan so that they can accomplish a component of game play. For example, in the Portal games, you have to plan where you are going in order to place your portals so that you can finish a level. This category focuses on game play.

**Participation**. A game is well designed if both strong and weak students want to play it. The educational components of the game are set up in a way that does not exclude weak students or bore strong students. That is, the problems are rich enough to allow students of all levels the opportunity to attempt the problems. This category focuses on the problems posed.

**Engagement/motivation**. Game elements interest students. Examples include (but are not limited to) an interesting narrative, working toward a goal, competition (with self or others), and increasing level of difficulty. This category focuses on game play.

**User friendliness and ease of play.** Here we are looking at whether the game was frustrating or not. Did you understand what your goals and objectives were? If you were told to accomplish a task, were clear instructions given on how that could be done? Is the level of the game play at a reasonable level?

## Definitions for Rubric

**Event.** This is any component of the game. It can include explicit or implicit problems presented, strategies needed to solve the game, or anything else that is a feature of the game.

**Substantial event.** This is a component of the game that would either take substantial game play time to do (20–50% of game time) or is a primary component of the game (e.g., a theme that runs throughout the game but doesn't necessarily take up a lot of game play).

**Distinct events.** These can include the same type of problem but in different contexts. For example, if all of the questions are solving real-world problems (e.g., applying percentage), but each of the situations is different (e.g., adding tax, determining how much is saved, determining new price), then these are considered distinct events.

If the game involves solving one very rich problem, we take that to be more than one substantial event.

## Appendix B

### Cognitive Rubric

To evaluate the type of knowledge needed to complete these games, we will use the following table taken from "A Model of Learning Objectives" by the Centre for Excellence in Learning and Teaching at Iowa State University (2011).

**Table A.** The Cognitive Processes Dimension: Categories, Cognitive Processes (and Alternative Names)

| Lower-Order Thinking Skills | | | | Higher-Order Thinking Skills | |
|---|---|---|---|---|---|
| Remember | Understand | Apply | Analyze | Evaluate | Create |
| Recognizing (identifying) | Interpreting (clarifying, paraphrasing, representing, translating) | Executing (carrying out) | Differentiating (discriminating, distinguishing, focusing, selecting) | Checking (coordinating, detecting, monitoring, testing) | Generating (hypothesizing) |
| Recalling (retrieving) | Exemplifying (illustrating, instantiating) | Implementing (using) | Organizing (finding coherence, integrating, outlining, parsing, structuring) | Critiquing (judging) | Planning (designing) |
| | Classifying (categorizing, subsuming) | | Attributing (deconstructing) | | Producing (construct) |
| | Summarizing (abstracting, subsuming) | | | | |
| | Inferring (concluding, extrapolating, interpolating, predicting) | | | | |
| | Comparing (contrasting, mapping, matching) | | | | |
| | Explaining (constructing models) | | | | |

Note. Table 1 adapted from Anderson & Krathwohl, 2001, pp. 67–68.

It is our belief that each of the above knowledge types is nested within each other. Like a matryoshka doll or Russian nesting doll, the knowledge types on the left are part of the knowledge types above it. That is, we cannot apply knowledge without first remembering and understanding the knowledge.

For each game, we determine how many problems exist in the game. Then each problem will be given a score from 1 to 6, where 1 means that the most knowledge that the player needs to apply for that problem is remembering, and 6 means that the most knowledge that the player needs to apply for that problem is creating. If 6 is given, that also means that the player has also used all of the other knowledge types to complete the problem.

Once each of the problems has been given a score, the mean of the problems is the score for that game. For example, if a game has three problems in which two problems apply knowledge (score of 3 each) and one problem analyzes knowledge (score of 4), then the overall score for the game is 3.3.