How Can Teachers Use Video Games to Teach Their Students Mathematics?

A Pew report published in 2008 reported that 97 percent of teenagers play video games of some type (Lenhart et al., 2008). The U.S. Department of Education's *Transforming American Education: Learning Powered by Technology* (2010) suggests video games can support a range of teaching and learning activities in school, from embedded assessment to engagement with locally relevant issues. This recommendation echoes research describing how well-designed video games can simulate professional practices and model real-world problem solving (Gee, 2005, 2007; Salen, 2008; Shaffer, 2006a; Squire, 2006). Recently, a survey of elementary and middle school teachers already using video games in their classrooms found that nearly one-fifth teach with video games *every day* (Millstone, 2012).

Concerning mathematics education, we suggest it is necessary to ask: How can teachers use video games to teach their students mathematics? Our primary concern raises additional questions about how teachers select and evaluate video games, and the various types of video games suitable for mathematics instruction. We address these questions by reviewing current research on video games and mathematics education, and then detailing how to find specific mathematics video games. After highlighting a case of video game play supporting statistical reasoning, we discuss how to adapt video games to support classroom teaching, and we then consider the future of teaching mathematics with video games.

Background: Video Games and Mathematics Education

For many teachers, their introduction to teaching mathematics with video games was *Math Blaster* (Davidson & Associates, 1983), "A standard drill-and-practice-type instructional mechanism . . . within a shooter game idiom" (Ito, 2008, p. 93). Introduced in 1983, *Math Blaster* was a best-selling piece of software; today, mathematics video games are a broader, dynamic, and profitable enterprise. Video games have been designed across grade levels and to meet Common Core State Standards for Mathematics (2010) and National Council of Teachers of Mathematics (2000) standards. They now range from the mobile drill program *Flash Math* (Kiger, Herro, & Prunty, 2012) to narrative-based virtual worlds like *Quest Atlantis* (Gresalfi, Barab, Siyahhan, & Christensen, 2009).

Because definitions of "game" are broad and contested (Salen & Zimmerman, 2003; Schell, 2008), in this brief we consider video games to be "imaginary worlds, hypothetical spaces where players can test ideas and experience their consequences" (Squire & Jenkins, 2003, p. 8). This definition is consistent with a general consensus that video games are more than digital tools; video games are designed environments, or possibility spaces (Squire, 2008), that support learning across multiple social spaces, shared practices, and emergent forms of knowledge (Barab, Gresalfi, Dodge, & Ingram-Goble, 2010; Gee, 2003; Shaffer, 2006b). Our understanding of video games contrasts with digital simulations like *Geometer's Sketchpad* (Key Curriculum Press, 1991; e.g., Knuth, 2002; Leong & Lim-Teo, 2003) or "cognitive tutor" systems (e.g. Anderson, Corbett, Koedinger, & Pelletier, 1995), which primarily support consistent and accurate means of interacting with mathematical objects and or notations. Video game play, on the other hand—like play in general—affords positive affect, nonlinearity, intrinsic motivation, process, and free choice (Johnson, Christie, & Wardle, 2005; Vygotsky, 1978).

Unlike established research about the impact of video games on students' science learning (e.g. Clarke & Dede, 2009; Gaydos & Squire, 2012; Squire, 2010), only a handful of empirical investigations have explored how video games influence students' mathematics experiences and understanding (e.g., Harris, Yuill, & Luckin, 2008; Ke & Grabowski, 2007; Kebritchi, 2008). Young and colleagues (2012) recently examined the pedagogical value of video games in respect to student achievement. Nine studies from the mathematics gaming literature were included in their meta-analysis. Like previous reviews which identified a sparse literature base and insufficient research about instructional gaming among specific age groups (Mitchell & Savill-Smith, 2004), Young et al. (2012) suggest better "correspondence" be developed between a game's objectives and students' mathematics learning activities. Teaching mathematics with video games does not invariably equate to students learning mathematics from video games. In other words, the results are mixed.

Ke & Grabowski (2007) found that fifth graders who played video games outperformed non-gaming peers, yet only those who played games cooperatively (rather than competitively) had effective gains in mathematics understanding and positive changes in attitude (as measured by a modified version of the Attitudes Towards Maths Inventory; Tapia, Marsh, & George, 2004). For high school students, playing *DimensionM* when aligned with online modules and classroom teaching increased mathematics achievement in comparison to non-gaming students; however, gameplay did not improve motivation to learn mathematics (Kebritchi, 2008). Kebritchi, Hirumi, and Bai (2008) found statistically significant gains for high school students who played video games; their average achievement gain between two district exams was more than double that of non-gaming peers. Further, these students' teachers reported video games as "effective" learning tools because they were experimental, offered alternative teaching approaches, provided an engaging rationale for learning, and increased time on task. Nonetheless, trends persist across this literature; the success and failure of teaching mathematics with video games reflects many factors, including research design, game mechanics, teaching strategies, learning objectives, and context (Young et al., 2012).

The varied influence of video game play in mathematics classrooms is unsurprising: games are no magic bullet. Like Young et al. (2012), we believe that successful learning depends upon teachers developing and supporting "correspondence" between play and instruction. Effectively teaching mathematics with video games requires teachers who can develop, support, and reflect upon how any game corresponds to instructional goals and student learning needs. In sum, mathematically meaningful gameplay is the result of thoughtful and creative teaching. But how does a teacher go about finding mathematics video games to support teaching and learning in his or her classroom?

Finding Mathematics Video Games

Imagine a veteran mathematics educator eager to refine her practice. Alternatively, what of the "digitally able" first-year teacher (Starkey, 2010), a novice confident in her ability to adapt a range of new technologies to communicate, problem-solve, play, and share information about teaching and student learning. How might either teacher identify what makes gameplay effective in a mathematics classroom? What will either perceive to be the advantages of video games in contrast to more traditional instructional strategies? Can common pitfalls be avoided, hallmarks of success recognized, and challenges mitigated? Each of these educators can easily visit the "Education" section of Apple's App Store and search for "math games." As of May 2014, this search gave 219 results. Some games are free while others are cheap, and the available games cover a range of content areas and grade levels,

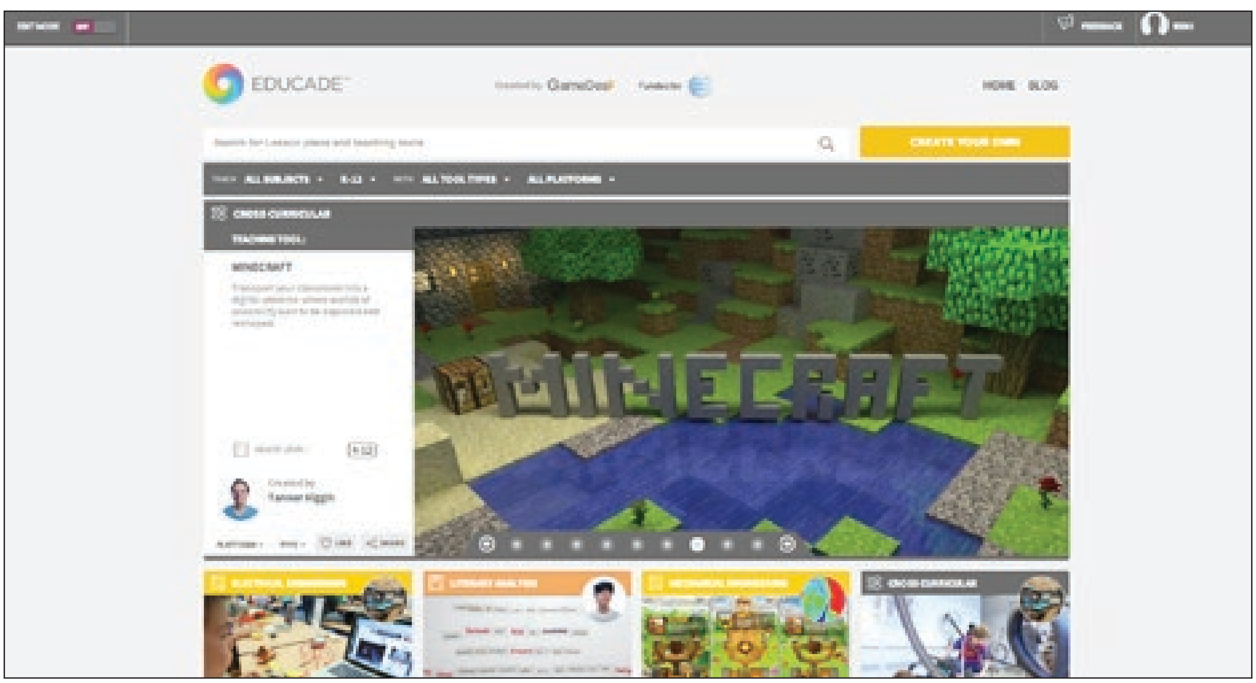

Fig. 1. Screenshot of Educade homepage

with many claiming to dramatically improve students' learning. Where might these teachers go to find well-designed video games, related curricular materials, and—perhaps most importantly—a community of professionals who can support implementation and refinement of teaching mathematics with video games?

Enthusiasm about video games and learning has resulted in the growth of many online resources and communities, as well as offline conferences and professional learning events. Websites such as GameDesk's Educade (http://educade.org) and Common Sense Media's Graphite (http://www.graphite.org) provide free game reviews, lesson plans, teaching tools, and other resources—many of them authored by teachers. Many educators have also created and joined online communities devoted to single games. For example, the game Minecraft (Mojang, 2009) has inspired MinecraftEdu (http://minecraftedu.com), an online community and collaborative effort promoting affordability and school accessibility. Additionally, the Playful Learning Initiative (http://playfullearning.com) supports an online knowledge base of video games, facilitates regional and national partnerships and professional learning summits, and is guided by an advisory board of K–12 educators.

As new mathematics video games are designed, so too will the number of websites, online communities, and other resources proliferate. Each website and online community has different characteristics; accordingly, we offer a brief outline of how to find relevant games using Educade (see fig. 1).

A search bar at the top of the website may be used, for example, to find games focused on middle and high school algebra. Seven results are presented. Four are "teaching tools," or information about specific games and resources for teaching mathematics. The remaining three are "lesson plans" focused on implementing games according to specific learning objectives. One "teaching tool" is *Dragonbox* (WeWantToKnow, 2012). Accompanied by two lesson plans, *Dragonbox* is likely a useful resource, and selecting the game leads to additional information. A screenshot from *Dragonbox* is included as figure 2.

Dragonbox is robustly described with text, images, a video, as well as information regarding algebraic content, appropriate grade levels, platforms supporting gameplay, and how teachers can implement the game. There are also two relevant lesson plans, and a link to the official *Dragonbox* website. While we strongly recommend *Dragonbox* (particularly for mathematics teachers newly interested in video games), more than a few poorly designed mathematics games are also available. We advise playing a demo before purchasing any mathematics video game. If a game does not have a freely available demo, request one from the company. In our experience, a company unwilling to share a demo may be concerned that they are marketing an inferior product.

After downloading the demo, play it! While developing

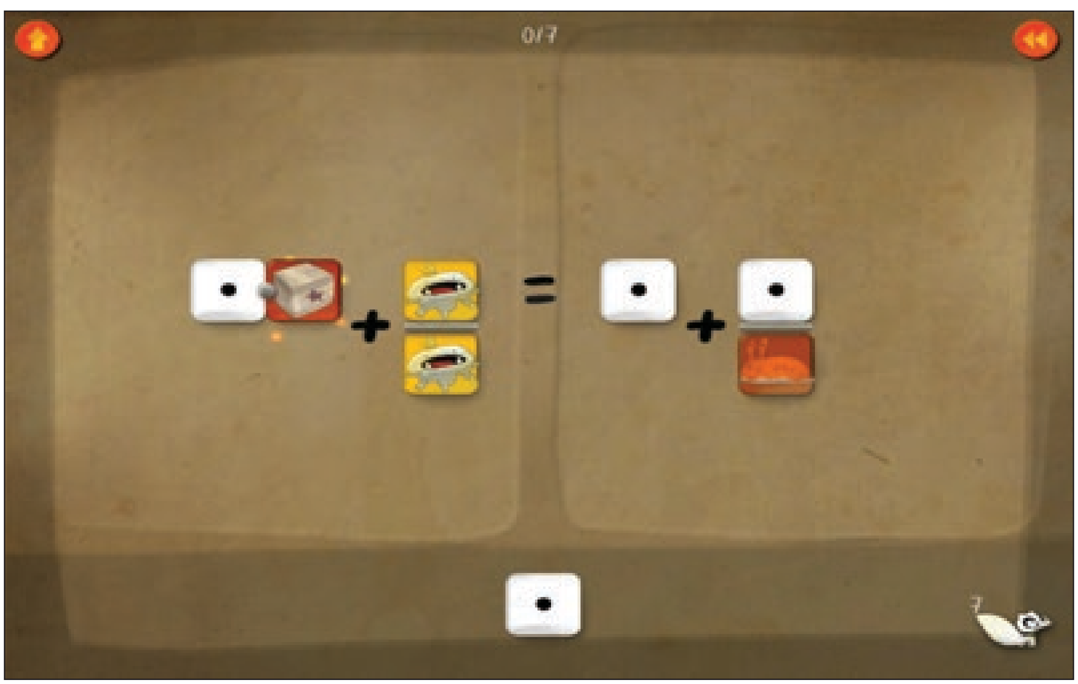

Fig. 2. Screenshot of a level from *Dragonbox*

ideas about how the game fits with classroom teaching, request funding to purchase the full game for classroom use. Consider how the game aligns with curricula, and the "correspondence" among students' play, mathematics content, and instruction. Will students play in the classroom, after school, or at home? When playing after school or at home, make sure that a computer lab is available and that the game is properly installed so that all students have access to it.

Finally, it is crucial to fully play any game before implementation. While playing, reference desired learning objectives and note which are supported by play and which are not. Consider how the game supports standards and curricula, and what lesson and unit planning could connect student gameplay with learning objectives. Teachers who are eager to consult models of classroom teaching and learning can find online communities of teachers and designers (listed earlier) who openly share tales of triumph and failure. These stories can inform decisions about whether or how a game should be played. Accordingly, we now share a case study that highlights ways of connecting gameplay to classroom teaching.

Case Study: Statistical Reasoning and *World of Warcraft*

Teaching mathematics with video games need not conjure up aged images of *Math Blaster;* classroom teachers are adapting various gaming environments to support the development of sophisticated mathematical investigations. Consider the case of Scott McClintock, a statistics teacher at West Chester University in West Chester, Pennsylvania. Writing in NCTM's *Mathematics Teacher,* McClintock (2011) describes how the game *World of Warcraft* (Blizzard Entertainment, 2004; fig. 3, below) supported his students' understanding of statistical reasoning. A primary concern for McClintock had been data collection and analysis; he perceived issues of sample size and survey relevance to be pedagogical challenges for quality teaching and learning. However, with *World of Warcraft* McClintock realized he could address these challenges by creating assignments that engaged a "wide variety of statistical practices" (p. 215). One key to McClintock's successes—and his students' learning—was the opportunities for engagement and reflection found within the game world and also in class after gameplay ended.

Fig. 3. Screenshot of multiplayer battle Al'Akir in *World of Warcraft* (used with permission from Martin et al., 2012)

One assignment concerns the statistical concept of sampling. McClintock directed his students to survey the race and class of 50 *World of Warcraft* players in each of three different cities. Knowledgeable about the four different races and four different class categories possible for any given player, students sampled 50 players in the human capital, 50 in the elven capital, and 50 in a racially neutral city. After collecting data, students calculated the percentage of humans in each sample, and then determined which sample proportion most likely represented the true proportion of total human players.

Although *World of Warcraft* was not designed to teach statistics, a number of game features supported students' statistical reasoning. First, random sampling methods would not work in this virtual context; instead, systematic sampling was possible as the race and class of a given player could be obtained through an unobtrusive mouse click. Second, the design of particular cities biases the sample; sampling in the human capital would likely overestimate the total proportion of humans, whereas sampling in the elven capital would likely underestimate the proportion. Thus, only in a race-neutral city could students obtain the least biased statistical sample. It was because of the game's contextual features that more sophisticated mathematics, about the probabilities of players' race and class, became possible. McClintock also addressed the importance of continuing to support students' investigations beyond gameplay.

Reflecting upon his own limitations, he suggests teachers provide written feedback to students about findings, encourage students to ask questions of their data, and conduct iterative rounds of data collection and analysis back in *World of Warcraft* to test new hypotheses. Ultimately, McClintock argues that both game features and teachers' pedagogy can appropriately support students' learning of complex statistics, and that teachers should "consider how we might adapt [video games] to enhance the reach and scope of the classroom" (p. 217).

Discussion: Playing and Adapting Video Games for Teaching Mathematics

The intent of this brief is not to support any mathematics teacher in *only* visiting an online database, downloading a game and related materials, and then having students play "for fun" or as a "reward" after completing another assignment. Rather, we advocate *adapting* video games to complement the characteristics of a classroom. McCall (2011), writing about his own use of games in the classroom, argues, "Successful game-based lessons are the product of well-designed environments. Teacher/designers must thoughtfully embed these games in an environment and set of learning activities where students, learning tools, and resources work together in pursuit of the desired outcomes" (p. 61).

Robust mathematics education has never been achieved through the blind adoption of new curricula, tools, or methods devoid of teachers' skillful facilitation; video games are not—and, we believe, will never be—an exception. Teaching mathematics with video games will require that teachers deftly consider trends, limitations, and the insights of case studies such as the one noted above; make professional judgments relevant to local context; and reflect upon the successes and challenges associated with teaching and student learning.

We suggest that educators interested in teaching mathematics with video games recognize the substantial effort and intellectual engagement required of such an endeavor. Learning to play any game to support learning – and, in particular, a mathematics video game – entails professional behaviors similar to acquiring any new teaching method: research, planning, implementation, reflection, and iteration. Teachers should investigate games and related teaching resources. Game play should be a central element to any teachers' personal research and learning. Curricular materials, lesson plans, and assessments should also be prepared before classroom implementation, yet remain flexible enough to be revised iteratively. Furthermore, it may be advantageous for teachers to join online professional-amateur ("pro-am") gaming communities, like those associated with *Minecraft,* in order to discuss experiences, share insights, and grow a professional network of teachers-as-players.

The Future of Game-Based Mathematics Education

As both literature and popular media indicate, teachers and their students are playing and increasingly designing video games (Squire, 2011). With a growing number of teachers writing about their own experience designing and teaching with video games (e.g. Elford [blog]; McCall, 2011), we believe this is a very exciting time to be a mathematics educator interested in using video games (and other games) for learning. Classroom teachers are beginning to refine how researchers and designers create mathematics video games, so content and gameplay both align to standards and also adapt to individual students' learning needs (e.g. Riconscente, 2011). What new forms of pedagogical, technological (cf. Mishra & Koehler, 2006), and mathematical knowledge for teaching (cf. Ball, Thames, & Phelps, 2008) might teachers demonstrate when teaching with video games across both formal and informal settings? Might virtual game worlds, like World of Warcraft, become a communal mathematics "third places" (Steinkuehler & D. Williams, 2006) among networked learners around the world? And how might playful pedagogy and game-based curricula alter how researchers and practitioners understand "ambitious" instruction (cf. Lampert et al., 2010)? As Young and colleagues (2012) suggest, the future of game-based education will be shaped by educators and researchers who collaboratively examine "how gaming combined with instructional facilitation by a master teacher affects engagement, student behavior, and overall academic achievement" (p. 83). It is an exciting time to be an educator interested in teaching mathematics with video games.

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