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Our Princess Is in Another Castle: A Review of Trends in Serious Gaming for Education

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Do video games show demonstrable relationships to academic achievement gains when used to support the K-12 curriculum? In a review of literature, we identified 300+ articles whose descriptions related to video games and academic achievement. We found some evidence for the effects of video games on language learning, history, and physical education (specifically exergames), but little support for the academic value of video games in science and math. We summarize the trends for each subject area and supply recommendations for the nascent field of video games research. Many educationally interesting games exist, yet evidence for their impact on student achievement is slim. We recommend separating simulations from games and refocusing the question onto the situated nature of game-player-context interactions, including meta-game social collaborative elements.

Keywords: video games, meta review, situated learning.

Since the introduction of home computers and gaming consoles in the mid-1980s, school-aged children have spent more time with electronic media than ever before. Video game use has risen such that 60% of individuals aged 8–18 were playing video games on a typical day in 2009, compared to 52% in 2004 and 38% in 1999 (Rideout, Foerh, & Roberts, 2010). With so many students and teachers immersed in video gaming, our team set out on an epic quest to investigate the connection between video game and classroom achievement and to establish the unique affordances and benefits video games may have for school learning. The following is a review of the literature aimed at examining the use of video games as part of K–12 curricula that includes both major findings and recommendations about what we believe are necessary steps to support progress in the nascent field of video games research.

There are already many games designed with educational objectives in mind. Entire virtual worlds, such as those using Active Worlds (e.g., *Quest Atlantis* and *River City*) and areas of *Second Life*, use avatars to immerse students in 3D learning environments. Others present gaming environments that focus directly on science (e.g., *Physicus*, *Geoworld*, *Virtual Cell*, *Sneeze*, *World of Goo*), mathematics (e.g., *DimensionM, ASTRA EAGLE*), languages (e.g., *My Spanish Coach*), or history (e.g., *Civilization*, *Oregon Trail*, *Assassin's Creed*). There are also many games that focus on more general skills useful in school, such as spatial problem solving (*Portal*), logic (*L.A. Noire*), and mental rotation skills (*Tetris*). Most have the potential to be fun and immersive, with the ability to engage students outside the space and time reserved for class. They can be collaborative and massively multiplayer, they can be customized and/or configured to the needs of particular students and educators, or adapted to individual interests, and they can unfold as interactive fiction and be designed in ways that fit the constraints of the school day. From *Lemonade Stand*, *Oregon Trail*, and *Carmen Sandiego* to the previously mentioned 3D avatar-based virtual worlds, we sought to determine whether or not the overarching technology had reached enough of a "tipping point" in the past 30 years to support the claim that video games can enhance classroom learning.

We initially took a conservative approach, seeking to conduct a meta-analysis of classroom studies that evaluated experimental and comparison groups to provide insight into the world of educational video gaming. Quantitative investigation, we thought, would yield net effects for video game use in the classroom as compared to the application of traditional instructional methods. We targeted video games as related to academic achievement gains, specifically, and, with this focused objective, undertook our review with the enthusiasm of Mario diving into a green warp pipe as he begins his adventure. As both educators and gamers (not necessarily in that order), we hypothesized that educational video games, in general, would have a positive effect on a broad range of learning outcomes including engagement, motivation, content mastery, and sustained interest in the subject area.

Our initial search included academic journal articles, dissertations, thesis papers, and research reports on the use of video games in the classroom relating the use of video games to classroom achievement, and we sorted each resource according to its content and method of investigation. With enough pretest–posttest–control group quantitative analyses, we supposed that we could conduct our review with an empirical meta-analytic focus. However, in the absence of sufficient empirical research comparing knowledge gains from video games to different modes of instruction, we were forced to expand our scope to include studies that used quantitative, qualitative, and mixed-methods designs, as well as case studies and conceptual articles that described theoretical best practices for use of video games in the classroom. Although this second phase brought forth many articles only tangentially related to our goal of establishing a connection between video gaming and achievement, it yielded several articles whose collective trends gave us insight into what must be done to make empirical video gaming research more accessible to the academic community.

After initial analyses, we determined that, to date, there is limited evidence to suggest how educational games can be used to solve the problems inherent in the structure of traditional K–12 schooling and academia. Indeed, if you are looking for data to support that argument, then we are sorry, but your princess is in another castle. To make substantial progress, we believe that current methodologies must extend beyond their current parameters to account for the individualized nature of game play, acknowledging the impossibility of the same game being played exactly the same way twice and establishing that game play may need to be investigated as situated learning. The research and assessment measures for targeting video games through extensive time-coded log files of game play (accounting for the dynamics of multiple players in rich contexts) must be advanced and developed before such information will be useful to researchers and instructional designers.

Despite this setback, we offer summaries of the trends in video game research we did find, categorized within the following individual content areas: mathematics, science, language learning, physical education (PE), and history. We conclude by suggesting future directions that educators and researchers may use to drive the implementation and study of video games in the classroom. It is our hope that this effort provides what guidance could be culled from the nascent research on video games in schools, representing the first of many castles to conquer as research on video games in learning confronts the major bosses of analyzing complex multi-player interactions, assessing nonlinear dynamics, integrating space and time (where and when) into what students learn, and conducting research that accounts for not only game play itself but also the rich social interactions of the affinity groups that emerge around each game.

What Is a Game Versus a Video Game?

Can a multiple-choice quiz be a game? What about a crossword puzzle? Juul (2005) defined games as having six features: (a) a rule-based formal system, (b) variable and quantifiable outcomes, (c) different assigned values for different outcomes, (d) an outcome influenced by the efforts that the player exerts, (e) players feeling emotionally attached to the outcome, and (f) consequences of the activity that are negotiable. Given the wide variety of games—from single-player to multiplayer board games, strategy games, card games, and arcade games; from online role-playing games to first-person shooters; from console games to computer-based massively multiplayer role-playing games—it seems unlikely that we could identify the generalized educational affordances of all activities that we identify as games.

However, because games have historically been used as tools for enculturation, the use of games in schools is often viewed through a sociocultural framework. Games and play are an essential part of child development. Vygotsky (1978) highlighted play as the means for children to develop abstract imaginative thinking and realize goals that they could not yet achieve in real life. Vygotsky gave a classic example of a 3-year-old unable to ride a horse but who sits on a stick and imagines riding as a form of wish fulfillment. Children use games that imitate war or play "house" to mimic the adult activities for which they must ultimately prepare; ergo, *Civilization IV* or *World of Warcraft* (*WoW*; equal to war games) and *The Sims Online* and *TirNua* (the virtual equivalent of playing "house") can be said to have obvious sociocultural and educational affordances for the simulation of, enculturation to, and learning about adult activities.

Under these presumptions, we chose to further define games by utilizing the criteria set forth by the Joan Ganz Cooney Center at Sesame Workshop, which partnered with the U.S. Department of Education to promote the 2011 Science, Technology, Engineering, and Math (STEM) Video Game Challenge. In their report on using games for learning and health, Thai, Lowenstein, Ching, and Rejeski (2009) referenced Klopfer, Osterweil, and Salen (2009) to define a game as "a voluntary activity structured by rules, with a defined outcome (e.g., winning/losing) or other quantifiable feedback (e.g., points) that facilitates reliable comparisons of in-player performances" (p. 11). In particular, our research was focused on learning games. In their original report for the Education Arcade at MIT, Klopfer et al. (2009) defined digital-learning games as those that

> target the acquisition of knowledge as its own end and foster habits of mind and understanding that are generally useful or useful within an academic

> context. Learning Games may be associated with formal educational environments (schools and universities, online or off), places of informal learning (e.g., museums), or self-learners interested acquiring new knowledge or understanding. (p. 21)

We preferred this definition of learning games because it eliminates simulations and digital visualization tools that are not true games but is broad enough to include alternate reality games (ARGs) and other activities that can be more traditionally defined as video games (or those that possess elements that make them video-game-like).

By eliminating simulations from our review, we acknowledge omitting a potentially very powerful hybrid class of activities that blends simulations with gaming mechanics. Simulations are designed to model real systems as veridically as possible, whereas the object of games is to score points and win. Modeling is a main approach to science but is known to be difficult for science students to pick up (see, e.g., Michigan's Hi-Ci group's work on *Model-It*; Metcalf, Krajcik, & Soloway, 2000). Although games often have elements of simulation within them, such that game worlds "work" like the real world in respect to gravity and basic physics, for example, we suggest that it is important to distinguish the educational affordances of simulations and modeling software from the affordances of video games. As such, the current review focused on games per se and chose to leave the review of educational simulations and modeling tools, even those with some game elements, as a separate undertaking.

What Is Fun?

Fun is not just something amusing, nor is it simply the result of a leisure time activity. According to Csikszentmihalyi (1990), even assembly line workers can have fun on the job (he referred to it as "flow") by establishing hourly goals and trying to beat their best time. If work can be fun, games can also be work (consider, e.g., professional sports). It is also possible to put contextual constraints on a situation such that activities that would normally be fun *must* be done at a certain time and place, rendering them less enjoyable activities. An example of this might be a teacher who requires her class to play 40 hours of *WoW* as homework, with students not doing so receiving a failing grade. Some students who may normally enjoy playing *WoW* might now find the exact same activity onerous, raising important questions about context and intentionality and bringing the conversation to how educational gaming can both be regularly engaging and feel less like work. Taking this social constructivist approach generated our first inkling that the answers we sought concerning the impact of video games on academic achievement might be addressing the wrong question and suggested that our princess might be beckoning from another castle on the distant horizon.

Literature Search and Method

Our review employed a two-phase search. The initial search surveyed the field using library databases (ERIC, Academic Search Premier, Communication & Mass Media Complete, Computer Source, Library, Information Science & Technology Abstracts, PsycARTICLES, Psychology and Behavioral Sciences Collection, PsycINFO) and bread-crumb searches from the reference lists of gathered articles (i.e., following the references from one article of interest to additional articles, etc.). Search terms included *video game*, *game*, *education*, *academic* *achievement*, *classroom*, *learning*, *students*, *computer game*, *affordance*, *group*, *motivation*, *collaboration*, *grades*, *MMORPG*, *play*, *violence*, *achievement*, *gaming*, *learning outcome*, *warcraft*, and *quest atlantis*. To be included in our initial search, an article had to both reference video games and assess some sort of student academic achievement as a dependent variable. From an initial set of 275 search results, color-coded tags were developed and applied to our search results as

TABLE 1
Tags with example articles

Tag	Example
Green—Highly usable studies	
(Affordances—Science) Any research that describes the educational benefits of video game play for learning Science	Bainbridge (2007)
(Affordances—Camaraderie) Any research that describes the educational benefits of video game play for building teams or collaborative skills	Chen (2009)
(Affordances—Language learning) Any research that describes the educational benefits of video game play for learning language	Zheng (2006)
(Affordances—Mathematics) Any research that describes the educational benefits of video game play for learning math	A. Harris et al. (2008)
(Affordances—History) Any research that describes the educational benefits of video game play for learning history	Moshirnia and Israel (2010)
(Affordances—PE) Any research that describes the educational benefits of video game play for learning physical education	Maddison et al. (2009)
(Affordances—Motivation) Any research that describes the educational benefits of video game play for motivating students to do school work	Dickey (2007)
(Affordances—Training) Any research that describes the educational benefits of video game play for training specific skills or behaviors (e.g., safe sex, driving tanks or planes, or firing missiles)	Pirius (2007)
(Comparison study) Any study that directly tests the use of video games against a standard curriculum	Arici (2009)
Orange—Studies of potential utility	
(Conceptual paper) Any research that discusses the issues of video games in education, but without collecting any new data	Warren et al. (2009)
(Attitudes) Any research that discusses the issues of student attitudes about or related to gender discrepancy, students views of gaming, or student self-reported effectiveness of gaming	Heeter et al. (2009)

(continued)

TABLE 1 (continued)

Tag	Example
(Player experience) Any research that whose primary purpose is describe the game player's experience	Browell (2008)
Red—Studies outside the scope of our focus	
(Psychology) Any research that focuses on the psychological impact of game play, such as addiction, epilepsy, ADD, etc.	Griffiths (2010)
(Economics) Any research that focuses on the economics of in-game play, or how game money and real money are related	Kock (2008)
(Physiology) Any research that focuses on the biological impact of gaming or how games affect physiological properties of the human body	Caplovitz and Kastner (2009)

described in Table 1. Tagged studies were then organized into five categories based on K–12 subject matter: mathematics, language learning or language arts, science, social studies or history, and physical education.

The second phase of our effort examined the five major content areas as separate categories, uncovering new literature through multiple database, bread-crumb, and online (including Google Scholar) searches, and expanded the population to include undergraduate students. To be added to the Phase 1 search results, Phase 2 results had to reference one of the specified subject areas (mathematics, science, language learning, history, or physical education) and video games. The same tags were used for the secondary search as for the original search. Of the 88 articles uncovered through the Phase 2 search, 2 were tagged as Affordances—History, 3 as Affordances—Math, 9 as Affordances—Physical Education, 17 as Affordances—Science, and 22 as Affordances—Language. In combination, the Phase 1 and Phase 2 searches resulted in 363 relevant articles that were analyzed for inclusion in our review (a complete list can be found in the appendix online). Of the 363 articles, 39 met our final criteria for inclusion: 3 in history, 8 in math, 7 in physical education, 11 in science, and 10 in language learning.

We were concerned that our princess might be in another castle since included articles composed only about 10% of the identified 363 studies. One factor in our decision was the absence of a clear specification in many articles of specific gaming interactions as a treatment variable. This was an obstacle in justifying the inclusion of articles that may have otherwise been useful, particularly those that examined achievement qualitatively or emphasized social and health-related outcomes related to video gaming. A second factor was the frequent absence of a school-related dependent variable. In our conclusions, we address the complexities of games as a treatment variable that may lead to difficulties in taking an empirical approach to their study.

Major Content Area Findings

To establish the educational affordances of video games in the content areas of mathematics, science, language learning, physical education, and history, we first pinpointed relevant trends within each subject. These subject area discussions, taken as a whole, provide the basis for our later conclusions and are used to review the pedagogical value of video gaming with respect to achievement.

Mathematics

Video gaming in mathematics is characterized by specialized math games developed within and for controlled studies. They are cited in only a small number of articles and are not used in further research or replication studies. In our review of the math gaming literature, we initially identified an investigation by A. Harris, Yuill, and Luckin (2008) that addressed how video games may be used to effectively facilitate student collaboration on complex logic problems. The study included 34 primary school students aged 8 to 10 years, and the researchers examined the influence of mastery and performance goals on the nature of children's participation during video gaming. Each student was matched with a partner based on his or her goal orientation, and each pair spent 20 minutes cooperatively playing a logic-development game (*The Logical Journey of Zoombinis*). A. Harris et al. observed that students with different goal orientations interacted in different ways while solving mathematical problems and concluded that goal-focused instructions could be used to influence the nature and quality of children's partnered interactions, potentially improving long-term academic achievement.

Similarly, Mayo's (2009) study found that although many educators were not open to the idea of using video games in their classrooms, such programs increased achievement (as measured by standardized testing) from 7% to 40%, including high school algebra and college-level numerical methods. The learning outcomes increased by 7.2% when students (N = 193) played *Dimenxian*/*Evolver* to learn algebra, compared to lecture on the same material. When students played *NIU Torcs*, they spent more time doing homework by a factor of two or more, and they were able to create much more detailed concept maps than students exposed solely to lecture methods of instruction. Okolo (1992) reported roughly parallel results using a simple game, *Math Masters*, in a sample of 41 special needs students but found the positive effect was primarily only for students with high achievement motivation.

Kebritchi's (2008) work further supported the potential educative nature of video gaming despite establishing mixed results for the effects of mathematics video games on student motivation. Over the course of one trial, 10 high school algebra and geometry teachers were assigned to either a treatment or control group with a combined total of 193 high school students in Grades 9 and 10. Half of the students were assigned to play a game (*DimensionM*) based on their teacher's group membership (i.e., control vs. experimental). Results indicated that students who played the video games showed significant improvement with regard to mathematics achievement as compared to their nongaming peers, but there were no significant improvements found in relation to students' motivation. Prior mathematics knowledge, computer skills, and English skills did not appear to be significant contributors to the students' end motivation or mathematics achievement, causing Kebritchi to suggest that although the integration of games into the academic environment could potentially positively affect student outcomes, this outcome would require a number of design and implementation modifications, including, among others, (a) providing training programs for teachers and students, (b) ensuring access to computers and allocating sufficient time for video gaming, and (c) educating school administrators about the relative effectiveness of using video games in teaching mathematics.

To that end, Ke's (2008a, 2008b, 2008c; Ke & Grabowski, 2007) investigations into the use of the mathematics educational gaming package, *ASTRA EAGLE*, were targeted to address some of the aforementioned issues. According to Ke and Grabowski (2007), the *ASTRA EAGLE* games were "designed to reinforce academic standards for [fifth grade] mathematics required by the Pennsylvania System of School Assessment" (p. 252). They focused on the game-playing context in a sample of 125 fifth-graders with three different experimental structures: teams–games–tournament (cooperative learning), interpersonal competitive, and no game play. Ke and Grabowski found that both gaming groups (cooperative and competitive) outperformed their nongaming peers in achievement gains but that only the cooperative group showed affective gains toward mathematics. More specifically, students with low socioeconomic status (SES) saw the greatest affective gains in cooperative contexts. Ke's (2008a) study ($N = 160$) added an individual gaming group, and the findings were replicated: Gaming groups saw greater achievement gains than nongaming groups, and the cooperative gaming group saw the only significant affective gains (again, with low-SES making the greatest gains.

However, in Ke's (2008b, 2008c) two follow-up studies, there were contradictory results with regard to achievement gains. All four investigations highlighted the same affective gains for all gaming groups, and the 2008c study ($N = 358$) indicated that individual gaming contexts showed significant achievement gains over non-game-learning contexts as in two previous studies. Conversely, the 2008b study ($N = 15$) showed that students in all three gaming groups demonstrated a similar lack of achievement growth, prompting Ke to list a number of constraints on the use of video games in the classroom that we believe are worth noting (see Table 2).

As demonstrated in Ke's (2008a, 2008b, 2008c; Ke & Grabowski, 2007) and Kebritchi's (2008) findings, educational gaming in mathematics is not as simple as putting a student in front of a computer and expecting substantial achievement or motivational results. Rather, educational games need to be designed and researched with careful attention to contemporary learning theories, including customization of task difficulty to the learner's capabilities, metacognitive reflection on the learning taking place, and consideration of the rich situated interaction among learner, game environment and classroom environment. The studies by Mayo (2009), A. Harris et al. (2008), and Kebritchi (2008), which addressed all three areas of need, have led us to believe that learning and game objectives should be aligned in one-to-one correspondence, and the social interactions that make learning "situated" must be accounted for before the educational affordances of games can be fully described. Although the effectiveness of a single game's impact on a subset of learners may be useful in the short term, longer-term studies that focus on student, game, and context interactions should be undertaken. We explore these elements in greater detail in our final recommendations.

Science

The *Educate to Innovate Campaign*, cosponsored by the U.S. Department of Education, has invested greatly in the development of immersive, science-themed

TABLE 2
Constraints on use of video games for mathematics from Ke (2008b)

Constraint or concern	Rationale
Learning outside of the game play versus learning within the game play	"When facing a poor game design where the learning activities were not deftly disguised within the game world, participants reacted by deeming learning as a foe and chose to simply bypass it" (p. 5).
Wandering mouse—Random clicking	"The game's difficulty level should be appropriate with respect to players' levels, and game-based learning works best when new challenges are felt by learners to be hard but doable" (p. 6).
Learning situated within the game play	"Under conditions of high game goal commitment, individual players will enhance efforts and performance to game-based learning" (p. 7).
Gaming without reflection	"Most participants lacked a reflection process for performance analysis, new knowledge generation, evaluation, and integration, which are essential for learning as a cycle of probing the world—a major knowledge-construction format for game-based learning" (p. 7).
Play-based communication	"Collective game-playing facilitated peer communication . . . however, these peer communications were mostly play-based rather than learning-oriented" (p. 8).
Peer scaffolding is not naturalistic	"Most participants revealed no awareness or skills to produce cognitive elaboration or prompt for cognitive elaboration production" (p. 8).
Boys versus girls	"Boys tended to focus on game-related conversations; whereas, girls used communication more generally. . . . Computer game [*sic*] is a facilitator for social communication and girls enjoyed game-playing particularly when given opportunity to socially interact with others" (p. 8).
Quiet achiever	"Although it is generally accepted that computer games are engaging for many people, what is engaging to some people will not necessarily be engaging to others. Individual differences in learning style and personality traits such as competitiveness, curiosity, or sensation seeking may be predictive of preferences for game-playing environment, hence be predictive of learning effectiveness of certain game applications" (p. 9).

(continued)

TABLE 2 (continued)

Constraint or concern	Rationale
Offline (metagame) learning tools	Limited use of "offline to assist online-game-based problem solving" (p. 9).
Pencil with paper versus calculator	"Most participants only used calculators. The exceptions were the ones with more advanced math competency, who used paper with pencil. . . . Participants who did not use paper and pencil hence missed a handy mapping tool, a tool that can help with cognitive modeling by assuming the lower-level burden of keeping track of arithmetic calculations so that learners can focus on higher-order thinking of problem analysis and solving" (p. 9).
Instructor's guidance	"The value of the instructor in scaffolding learners is a critical (and somewhat overlooked) component in the use of educational games, as are learner support strategies such as online help, cues/prompts, informative feedback, and other activities" (p. 9).

video games intended to promote youth curiosity and engagement in STEM, with the intent of increasing the number of college graduates in science-related fields (E-Line Media, 2010). However, despite a decade of research emphasis on STEM education, there has been little peer-reviewed literature published in game-based learning for science, and that which already exists, like that for mathematics, is not consistent in terms of activities being monitored, learning outcomes assessed, or types of science-based gaming being used as the treatment variable. This lack of consistency aligns with the National Research Council's (2011) report showing inconclusive findings on the effects of science video gaming on academic achievement. After vetting the content area research to remove articles concerned with non–video game simulations and issues unrelated to learning science or behaving as an actual scientist, we discovered only 11 science video gaming studies relevant to our initial metareview objective; of those, only 5 contained any empirical data with academic achievement listed as the primary dependent variable.

The most positive outcomes came from a study by Barab, Goldstone, and Zuiker (2009) and two related dissertations by Zuiker (2008) and Arici (2009) that underscored the value of three-dimensional avatar-based curricula on performance-based transfer tasks following interactions with the science-based subzones of *Quest Atlantis*. Data indicated that middle school students (Grades 6–8) in the game-based version of the course performed significantly better on related standardized tests than did their peers in expository textbook and descriptive framing versions of the class, leading the authors to express their interest in furthering game-based research in STEM fields. In addition, other science-related zones of

Quest Atlantis have shown potential benefits for science achievement, and two unrelated investigations on middle school science achievement have resulted in similar outcomes for a mobile phone problem-solving application ($N = 227$) and a physics game, *SURGE* ($N = 280$); however, the lack of statistical significance in the mobile phone study (Sanchez & Olivares, 2011) and modest power (0.1066) in the physics study (Clark et al., 2011) limit their impact on science gaming as a whole (Anderson, 2008).

Moreover, D. Harris's (2008) research on the academic value of the ecology-based massive multiplayer online game *Web Earth Online* yielded the opposite effect in a sample of 159 sixth-graders, illustrating a need for game researchers to explore exactly the game mechanics and related interactions that contribute to achievement gains. Although participants in both the experimental and control groups showed overall growth during the application of the game, participants in the experimental group tended to have statistically significant lower test scores than their peers in the versions of the class run by a researcher or teacher. D. Harris went on to suggest that the engagement benefits of utilizing video games in a science education environment may make the effort worthwhile but that the situated environment within the game universe appeared to accomplish less than traditional forms of instruction with regard to traditional test performance.

Similarly, Annetta, Minogue, Holmes, and Cheng (2009), studying 129 males and females aged 14 to 18 years old who played computer-based *MEGA* games, found no statistical impact on achievement on a genetics unit even though their engagement increased. Wrzesien and Alcañiz Raya's (2010) investigation into the use of a Spanish science-based game, *E-Junior*, provided no statistically significant evidence for achievement gains in a group of 48 middle-schoolers. This led them, like D. Harris (2008), to suggest that although science gaming probably yields benefits, constraints on the classroom environment and the short time frames of studies have made it difficult to discern any immediate correlation between game use and academic success.

Although our analysis uncovered no literature discussing socially driven achievement in massively multiplayer games like *WhyVille* and *Quest Atlantis*, our research in language learning has led us to believe both games offer students the tools necessary to explore and inquire about various facets of Science. Such benefits would be consistent with Vygotsky's (1978) co-labor within the zone of proximal development. Reliance on collaboration and inquiry is a part of engaging with material as an actual scientist would, meaning that social interaction in the game environment could potentially model the profession. Although additional research is scant, preliminary data suggest that *WhyVille*, in particular, has presented a successful medium for stimulating interest for both minority and female populations, suggesting that there may be some social learning significance for those groups (Dede, Ketelhut, & Nelson, 2004).

It is worth noting that a majority of video games across the science education literature appear to include only science-based activities and events that may be detrimental to the long-term effectiveness of embedded inquiry-based learning. Many games isolate science topics throughout their respective virtual worlds without consistency or underlying curricular rationale, whereas anchoring exploratory investigations with essential questions or systematic learning objectives has been shown to be of value (Cognition and Technology Group at Vanderbilt, 1992).

Although these strategies may be effective for teaching individual concepts such as vector fields (*WhyVille*) or gravity's influence on trajectory (*Mechanika*), the lack of coherence among concepts leaves players without context for much of the information they receive throughout game play. In addition, preprogrammed constraints on the gaming rule sets leave little room for student-driven experimental design, meaning that the types of experimentation being done are seldom user generated, nor do they address the earlier stages of problem solving, such as problem identification or problem definition (see Bransford & Stein's, 1993, IDEAL problem solving model).

These constraints undermine several of the fundamental principles necessary to foster student understanding of what it is to be a scientist. We speculate that the disconnect between students "doing" science and the instructional use of video games is the direct result of continued content disassembly and the lack of cohesive reassembly for the purposes of a spiral curricula. Such a breakdown does not correspond well with the comparatively useful gaming narratives utilized in language learning and history, and, as such, we recommend that well-constructed science games with well-crafted backstories be made to encourage process-driven inquiry that includes the narrative of science history and its future potential. These strategies may ultimately reduce the current trend of presenting science as an exercise in mastery of isolated facts.

Given these recommendations, it seems prudent to suggest implementing science games only in concert with good teaching. The transfer of science information from isolated in-game activities requires metacognitive scaffolding by a skilled educator who can encourage student reflection, provide students with thought questions that force them to reference the specific curricular science skills, and bridge content from the game into their real lives (Baek, Kim, & Park, 2009). Although the games themselves may be able to spur scientific thoughts, critical thinking, and knowledge construction, players often must be prompted to become metacognitively aware that they are using the scientific method and discussing scientific strategies that are rooted in the physical world before they become capable of utilizing those skills outside of the game.

Across the science video game literature, inconclusive results indicate how opportunities for video gaming in science education have yet to be fully explored and should be examined with specific emphasis on deep understanding over low-level vocabulary and concept memorization (Bainbridge, 2007). By designing science-based games that move beyond the lowest tiers of Bloom's taxonomy (Forehand, 2005), educators may yet be able to help their students achieve greater academic success through science gaming than they are currently able to with many of the narrowly focused products now under development. Barab et al.'s (2009) work with *Quest Atlantis* provides the strongest evidence that science-based gaming can be useful for achieving deep learning, but until there are studies that expand beyond tepid exploration of isolated science topics, the full benefits of situated science video games are unlikely to be manifest.

As an extension of this thought, we also posit that virtual worlds (which by their very nature do not include the manipulation of physical matter) should not entirely substitute for direct experiences with gravity, space, weather, fluid dynamics, and chemical reactions in the physical world, meaning that science-based video games may better enhance student achievement in the hands of skilled educators capable of employing kinesthetic laboratory supports that extend and support the virtual game content. Because certain physics-based games like *SURGE* and *Lunar Lander* do not present science material in a way that is directly transferable to the movement of actual physical objects, poorly constructed virtual environments may lack the means to illustrate the physical presence of game sprites as they would act in reality. As a result, they may introduce misconceptions that could interfere with the learning of concepts like force, momentum, and inertia, compared to probe-ware laboratory experiments in which students physically manipulate actual blocks, robots, and weights, or race cars. Based on evidence derived from D. Harris's (2008) work (and lack thereof in the other studies cited), we believe that without explicit bridging from the virtual world to the real world, video game experiences may make it much more difficult for learners to master the investigation of physical reality because, unlike the human interactions reflected in massively multiplayer online role-playing game (MMORPGs) and other types of video games, the structures built into some games do not directly match their counterparts outside of them. As a result, science-based video game designers may do well to incorporate body movement, in the form of activities via tools like the Xbox 360 Kinect, PlayStation Move, Wii, or other motion capture technology, to emphasize the interaction among forces (such as friction, torque, tension, and gravity) that cannot be wholly replicated with a mouse, keyboard, and computer screen.

It is clear from our analysis that more time must be devoted to the topic of science-based video gaming before larger trends regarding their impact are revealed. As with the National Research Council (2011) report, we do not believe science achievement can be conclusively linked to game use at this time. Like for mathematics, formative, real-time assessment and a clear 1:1 ratio of gaming and learning objectives (including those that entail learners mimicking career scientists) are necessary for science games to truly have a positive impact on deep learning and, subsequently, achievement. It is evident that *Quest Atlantis* has begun this journey, but more sophisticated, empirical studies must be employed for educators to capitalize on the complex interactions among learners, virtual environments, real environments, game narrative elements, game mechanics, and the integrated nature of the sciences.

Language Learning

Despite the fact that our investigations of mathematics and science literature described few positive effects for video gaming in education, our analysis in language learning was more promising. For the purposes of this review, language learning included, but was not limited to, language acquisition, second language acquisition, composition, and language arts.

In general, students can pick up language from various media. For example, Kuppens (2008), reporting on 374 sixth-graders in the Netherlands, showed that students who viewed movies or TV or played video games had statistically significant achievement gains in English grammar use when translating from English to Dutch (but not for Dutch to English translations). Similarly, a brief overview of the educational affordances of using video games to increase language learning has been reported by Peterson (2010), whose research focused on computer-assisted language learning through a number of games or simulations. With participants ranging from middle-schoolers to undergraduates, Peterson's (2010) review showed impacts of *Active Worlds* (Toyoda & Harrison, 2002), *The Sims* (Ranalli, 2008), and *WoW* (Thorne, 2008) on language learning. Common themes included video games as collaborative forums for negotiated meanings, learner-centered environments where experiential learning takes place, informal settings for purposeful communication, and contexts for enjoyable and engaging learning (Peterson, 2010).

Looking at the concept of general language learning, instructors appear to agree that the most powerful way to learn a language is through immersion in a culture where the language is used routinely to interact with others and the world. Of particular value for language learners are immersive experiences where nonnative speakers have the advantage of collaborating with native speakers (exolingual experiences) or with peers who are more fluent in the target language. Whether Chinese students coquesting with native English speakers in *Quest Atlantis* or native English speakers raiding in *WoW* on a German-speaking server, video games, particularly MMORPGs, can simultaneously provide a richly contextual immersive exolingual experience and provide rich chat log files for assessment and reflection. Zheng (2006) reported a case study of two Chinese students working for 10 weeks with two American students in *Quest Atlantis*. Analyzing chat logs, she reported that the Chinese students picked up grammar, usage, and vocabulary from chatting through a variety of interactions, including native speakers (a) finishing the sentences of nonnative speakers, (b) explicitly correcting grammar, and (c) providing feedback in other forms such as continuers and confirmations.

Leveraging video games to teach language in varying forms may be the most effective use of educational computer gaming to date. In addition to multiple studies indicating how video games can be useful in language instruction, some researchers present data that language-based gaming is viewed more favorably than other teaching methodologies, thus making it not only functional but also preferable. This quality alone establishes language learning as being substantially different from other academic subjects in the video gaming literature. Din and Calao (2001), for example, found that kindergartners' language skills (in the form of reading) increased for students playing educational video games compared to a control group using a standard reading curriculum, whereas math skills did not seem to improve with the implementation of gaming in the curriculum. Even though the same manipulation and educational video games were utilized for both skill sets, overarching language skills were bolstered by the video game despite no change in mathematical ability. It is important to note that the educational games were not worse than a standard teaching curriculum for mathematics in this sample; they simply were not preferable and did not appear to improve or add to the standard curriculum in any way. Similarly, Warren, Dondlinger, and Barab (2008) reported that the experimental group in a sample of 44 fourth-graders using *Anytown*, a zone in *Quest Atlantis*, showed statistically significant increases in motivation and language-arts-based standardized test achievement, whereas their teachers reported statistically significant decreases in time spent explaining and re-explaining directions.

However, as with other subjects we reviewed, language learning gains were not uniform across individuals or topics, but appear to result from a complex situated interaction of learner, game, and context. Robertson and Good (2003) reported game use by 42 sixth- and seventh-graders in Ireland who showed improvement in one element of writing (relationships) but not others (mood and personality). Zheng, Young, Wagner, and Brewer (2009) accounted for such variability in language learning through video game contexts, particularly massively multiplayer environments, by targeting the coaction of players within the game. Language allows players to negotiate meaning for action within the game context, and the power of video games for language learning is attributed to this grounded use of language in context.

Previous research suggests that the use of video games for language learning is so effective that there are many cases where video games used to teach language are capable of teaching students who are not even playing the game themselves but merely observing game play. This effect may lead to a large range of applications in a variety of social environments, especially within traditional classrooms with interactive whiteboards or other large screen displays. In an exploratory study by DeHaan (2008) to determine the effectiveness of a video game in teaching English as a second language to students at a rural Japanese university, it was found that university undergraduates who only observed game play learned significantly more than the students who were actually playing the games. Further exploration by DeHaan and Kono (2010) established additional evidence of this effect: University undergraduate observers were taught very effectively by the video game, learning more than twice as much vocabulary as the players themselves (DeHaan, Reed, & Kuwada, 2010). We posit that this may be the result of increased cognitive load for the player of the game as more attention may be required to play than to watch, and this split of attentional resources could limit the amount of learning experienced by a player of the video game compared to a bystander. However, for teachers who face the challenge of classroom management while getting students to play an educational video game, this research suggests that some effects of video games are inherently social, so not every student needs to play the game to receive the benefits of video game interactions.

The connection between video games and language learning leads us to wonder why language learning is so well matched to the learning affordances of video game play. As previously mentioned, we could suggest that video games bring learners into an immersive exolingual environment that has historically been the most efficient way to learn a language. Similar to moving to Italy to learn Italian, participating in a video game (e.g., playing or viewing as in DeHaan's 2008 and 2010 studies) places a learner into a social environment where learning the language is necessary for survival and success within the game. Although some may argue that language learning is more of an innate ability than learning mathematical or science concepts, we believe that it is reasonable to suggest that the immersive environments that video games create, and the human instinct to adapt and survive in those environments, can lead to more than just language learning.

The difference in findings between language learning and other subjects may also be attributed to differences in classroom pedagogy that are often associated with the various subjects: Language learning is inherently social and relies on socially contextualized pedagogy teeming with scenarios and interactive dialogs that differ from other content areas (e.g., science or math) with emphasis on direct instruction. Until other subjects also embrace and utilize the social-environmental aspects of education, we believe that they will benefit less from the instructional affordances of video games demonstrated in language learning.

Physical Education

Despite the moderate number of publications regarding physical education gaming in schools, very few quantitative, empirical investigations have been conducted to examine the affordances of physically active video games (exergames) such as *Dance Dance Revolution* or *Wii Fit* for PE. In their place, we considered literature that emphasized the exercise and motivational affordances of exergames. In addition, we sought out papers and articles that included strong testimonials such as those generated by whole school districts or projects involving a number of schools to bolster what little information could be found. Articles that contained only testimonials from single individuals or teachers in a single school were excluded from our review.

Our initial review highlighted a number of publications suggesting that exergames may provide about the same amount of physical activity as traditional forms of exercise. Mhurchu et al. (2008) conducted a preliminary study in Auckland, New Zealand, that consisted of a 12-week intervention involving 20 children aged 10 to 14 years. The children were randomly assigned either to a group playing exergames, which included *Sony EyeToy* or *Dance Dance Revolution*, or to a comparison group that did not play exergames. During the 12 weeks, the children either played exergames in place of traditional nonactive games or played nonactive games as the control. Physical activity was measured using an accelerometer and questionnaires and logs. The results suggested that children who played exergames were more physically active while playing fewer video games overall and also had decreased waist circumferences. This study's results suggested that, at least in the short term, children's activity level may be increased by using exergames. A follow-up study (Maddison et al., 2009) involving 330 children aged 10–14 years old measured additional parameters such as body mass index, percentage body fat, waist circumference, and cardiorespiratory fitness; preliminary results suggested similar findings favoring the use of video games.

Sell, Lillie, and Taylor (2008) studied 19 male college students playing 30-minute of *Dance Dance Revolution* (*DDR*) while their heart rates, ratings of perceived exertion, respiratory exchange rates, oxygen consumption, and total steps were recorded. Of the 19 participants, 12 were experienced *DDR* players (i.e., regularly and consistently played on the highest difficulty level) and 7 were inexperienced players (i.e., could consistently maintain play only at the lowest difficulty levels). The purpose of the study was to determine whether the players' experience with the game had an effect on their energy expenditure during the 30-minute session and to determine whether both experienced and inexperienced players could meet the minimal daily recommended levels of physical activity and energy expenditure. The results of the study found that experienced players showed higher levels of intensity and energy expenditure compared to inexperienced players. Experienced players also met or exceeded the American College of Sports Medicine's recommendations for moderate-intensity activity, whereas inexperienced players were able to achieve levels of only very light-intensity activity. These findings imply that as players continue playing and improve, they may experience higher daily levels of physical activity and fitness in the same amount of time. In addition, higher levels of enjoyment from playing *DDR* versus other traditional forms of exercise may make it easier for players to maintain consistent and regular daily exercise.

In addition, there have been several nonempirical testimonials of schools successfully applying exergames to their physical education curricula, including a West Virginia school system that incorporated *DDR* into its PE courses to great effect in 2004 (O'Hanlon, 2007). The program began as an at-home clinical study of 50 overweight children for whom the results were very positive, including improved arterial response to increased blood flow, an increase in aerobic capacity, and no weight gain. The participants were also "more willing to try new activities and invite friends over to play, and were more confident in participating in physical education classes" for the motivational affordances (O'Hanlon, 2007, p. 34). West Virginia's Department of Education then decided to implement *DDR* in 20 middle schools as a pilot program to gauge student interest and acceptance. When those programs produced positive results as well, the state mandated that all middle and junior high schools integrate *DDR* into their PE programs and that all of the state's gym teachers be trained in using *DDR*, with plans to expand into elementary and high school as well. Some schools also allow children to play before and after school as a supplemental activity as well as incorporating it into school dances. Research into the effect of these programs is forthcoming.

Schools in the United Kingdom have also begun introducing exergames into their PE curriculum (Hawkins, 2009). Five schools in Worcestershire, England, have used *Wii Sports*, which includes virtual bowling, baseball, and tennis, to successfully attract children who normally skipped PE to that class. Increased heart rates observed in the children playing the games showed that the games did provide cardiovascular exercise. Studies have also been done in Australia on the affordances of exergames in physical education (Souter, 2008). The Wii was introduced into a number of schools in Brisbane, Queensland, yielding positive results. As with results from other studies, it was observed that the games requiring physical input promoted exercise. Additional benefits were observed as well, such as students who were typically disengaged or had low self-confidence assisting others in games in which they were experienced.

Much as with language learning, video games in physical education have been found to have a net positive effect on students' motivations toward PE and exercise. The University of Cumbria in England conducted a study of 50 children aged 11 and 12 in which the children were asked to use exercise equipment while playing video games (Hawkins, 2009). However, they could play the game only while maintaining movement on the machine—if they stopped, the game would pause. The results showed that 90% of the children enjoyed that combination and "the games reduce[d] the boredom of exercise" (Hawkins, 2009, p. 10).

In the Brisbane study, Souter (2008) observed a number of factors that motivated students to participate in the exergames. For instance, students who were unskilled in, or were reluctant to participate in, other physical activities or other social events were able to comfortably play the Wii with a group and be successful at the games. That success then led to increased self-confidence, and some students were even motivated to try real sports after playing the Wii games. Additional results come from a study at the University at Buffalo in which overweight and nonoverweight children exercised in a variety of different ways using *DDR* (Epstein, Beecher, Graf, & Roemmich, 2007). The children could play the game using the interactive dance pad, play it using just a handheld controller, dance along with a video, or dance listening to music. The results showed that the children were more motivated to play *DDR* with the interactive dance pad over the other options because of the interactive nature of the game and that the increased motivation did not depend on the child's gender or weight status.

In sum, we believe exergames such as *DDR* and *EyeToy* appear to have a number of affordances for physical education that are not necessarily met via other instructional methods. It is important that engaging game play has the ability to attract students who may be hesitant to participate in traditional PE. Although there is currently insufficient empirical evidence to draw causal connections between gaming and physical education, we believe that new active video game technologies such as the Microsoft Kinect and PlayStation Move may introduce additional options for players to get physically involved while playing games and opportunities for game-based PE research. There are potentially interesting connections between exergames and cognitive research on embodied or grounded cognition (e.g., Barsalou, 2008, 2010) and a potentially rich and easy stream of data from these devices using their sophisticated camera systems and log files. These preliminary studies are encouraging and point to the need for longitudinal data, the need for researchers to collaborate with game designers, and other themes we address in our conclusions.

History

Much like their language learning counterparts, video games such as *Civilization IV*, *Call of Duty 4*, and *Age of Empires* offer students the opportunity to travel across time and space in the effort to bring history to life. Narratives embedded in historical content allow history games to offer unique affordances for reenacting, replaying, and gaining first person experiences within the realms of history and social studies. It should come as no surprise, then, that several studies highlighted history-based video games as an effective means of engaging students beyond traditional methods of history instruction (Devlin-Scherer & Sardone, 2010; Watson, Mong, & Harris, 2011), particularly when utilized in combination with skilled teaching, sound instructional design, and careful implementation (Lee & Probert, 2010; Squire, 2005).

Like other history educators turning to commercial video games set in historical contexts, Squire (2006) reviewed the *Civilization* series as a tool that instructors and learners can modify to re-create historical conflicts. These types of games allow history students to don the cap of a particular individual at a particular point in time in a specific social context, thereby incorporating many of the elements utilized in problem-based learning environments. Squire, Giovanetto, Devane, and Durga (2005) found that collaborative paired play worked particularly well in history classroom environments, with students reporting an increase in knowledge of maps, time lines, and historical terms, although the instructor needed to have a good deal of game play expertise to mediate and facilitate game play toward achievement gains.

However, Moshirnia and Israel's (2010) study reporting on 74 undergraduates stands out as one of very few empirical investigations in the realm of history video game research, using a Solomon three-group design to determine the learning effectiveness of a modified (or "modded") version of *Civilization IV*. The authors focused on the learner capacity to mod the look and abilities of characters, change the maps and displays, and create new text descriptions for new quests while retaining the production quality and capacity for engagement that are normally present in the game. At the study's conclusion, students were required to complete a history test in line with state standards to compare three conditions: (a) a pretest–posttest control group of students that received PowerPoint instruction, (b) a pretest–posttest group that played an American Revolution mod of *Civilization IV*, and (c) a posttest-only group that used the mod.

The results indicated no significant difference between the knowledge gained in the PowerPoint pretest–posttest group compared to the mod pretest–posttest group, although they did suggest evidence of a retention effect with the mod learners being more likely to recall information learned for one week longer than the PowerPoint group. In terms of delivery effectiveness, the game-playing participants underperformed on items that were based on information from the pop-up text, suggesting that the players did not pay as much attention to historical facts in the game text and cut scenes. Game players' performance on items that tested information gains from the appearance and abilities of the character sprites and the game displays was greater than on items testing information from the text pop-ups.

Foster (2011) showed positive results on the related social studies topic of microeconomics. Studying 26 fourth- to sixth-graders who played *RollerCoaster Tycoon 3* for 6 to 7 weeks, Foster found discipline knowledge test results improved pretest to posttest for both types of players: explorers and goal seekers. Foster also reported a difference in the motivational outcomes of the two types of players, with only the explorers valuing the game play, and suggested that this difference in the motivational outcomes of play should be further explored by game researchers, especially in light of equal benefits to academic achievement.

As history educators seek to gather more empirical data, researchers like Charsky and Mims (2008) have offered recommendations for instructors seeking to use commercial video games in the classroom, primarily suggesting that teachers partner with academic researchers to collect data during the implementation and use of video games in the classroom. Games like *SimCity*, *Age of Empires*, and *Civilization* can be integrated into the curriculum, even if their content differs from the traditional texts. Charsky and Mims suggested having students play the games and then comparing the content with historical accounts, pointing out the misconceptions and inaccuracies fostered by the game.

Akkerman, Admiraal, and Huizenga (2009) examined video game play combined with ARG elements, focusing on storification as the vehicle for learning history. In their work, storification is the active process of forming a narrative that links characters to their motives, intentions, actions, and outcomes. In this study, 216 secondary school students aged 12 to 16 used *Frequentie 1550*, a game that utilizes mobile GPS phones to teach the history of medieval Amsterdam. A "city team" of students explored the city using mobile phones to view a map of medieval Amsterdam and received text instructions and communicated with a "headquarters team," who used computers to gather information and guide the city team toward their objectives. Qualitative data and observations suggested that students did not pay much attention to the introductory coaching that provided backstory for the game (Akkerman et al., 2009).

During the game, students received messages that relayed narrative and objectives. Researchers observed that the students ignored the larger narrative and focused almost exclusively on task-based communication. Only after a few days of game play did the students pay more attention to the messages. The headquarters team that worked from a static location was able to gain a broader sense of the narrative of *Frequentie 1550*, but the city team juggled the learning experience with the experience of walking through the city, dipping in and out of the game flow experience. The city team lost a sense of the larger narrative, but when this team did re-create historical narratives, experience real buildings, and take pictures of real landmarks, a deeper and more meaningful understanding of a narrow piece of the narrative was gained. The blend of ARG, video game, and embodied experience provided a unique method of information delivery for historical content.

The observations from Akkerman et al. (2009), as well as Moshirnia and Israel (2010), suggest that adding text or historical information to gaming is not enough to foster learning. Knowing that gamers have a tendency to bypass information that is nonessential to completing game tasks, educators who develop historical games and mods might be better served by (a) using information delivery systems that are more integral to the game experience or (b) creating additional game elements that require reflection on the historical variables presented. Historical games can be designed to foster learning by allowing the students to take an authorship role and actively play through history rather than just reading about it. As with other subject areas reviewed, the needs for longitudinal data, collaboration among teachers, researchers, and game designers, and emphasis of the social metagame aspects of video games were noted.

Implications and Recommendations

The inconclusive nature of game-based learning research seems to only hint at the value of games as educational tools. Although there is likely a degree of utility that could be attributed to the use of video games in the classroom, the lack of cohesive themes in peer-reviewed articles suggests to us that something is missing. Many educationally interesting games exist, yet evidence for their impact on student achievement is slim. Many educational games have assimilated game features into the constraints of the school day, becoming 20-minute activities with associated work sheets that lack a multiplayer continuity and the extended engagement characteristic of games played for purely entertainment value. Such adaptations may mask the potential learning benefits of video games. Moreover, although it was our hope that video games for education would immediately be revealed as engaging and practicable tools for the improvement of student learning, we can report finding evidence only for language learning and, to a lesser degree, physical education. In other content domains, there appears to be a disconnect between the possible instructional affordances of games and how they are integrated into classrooms. Games are often multiplayer and cooperative and competitive; they engage players in several hours of extended play, allow rich "hint and cheat" websites to develop around player affinity groups, and are played from weeks to years. However, most schools trade off extended immersion for curriculum coverage, individual play, and short exposures, goals that are not well aligned with engaging video game play.

Despite the fact that video games are viewed positively by some teachers and even some administrators (Wlodarczyk, 2011), the stand-and-deliver teaching model designed as test preparation for high-stakes testing leaves little time for students to engage the curriculum in a meaningful way. Although teaching as telling is efficient, it does not often lead to deep understanding. Deep understanding takes time, reflection, and active engagement, which are strengths of video games, but meaningful engagement comes at the cost of efficiency and curriculum coverage. The following recommendations have been developed through our analyses to further the collective understanding and evaluation of video games as learning tools across the K–12 curriculum.

1. *Construct working definitions that will facilitate the separation of video games and simulations*. Educators and researchers have not clearly identified and catalogued the differences between video games of various types and simulations, particularly regarding the instructional affordances of discrete game mechanics. Although the research seems to support immersive software in the medical, military, and language fields, there are few labels that assist in differentiating among the various types of available programs or the continua along which they lie. Setting criteria for gaming, including overarching narratives, engaging characters, the presence of avatars, badges, and achievement reward systems, and/or multiplayer functionality, would go far in explicitly describing what type of software is being utilized in each study. For the purposes of maintaining generalizability between content and research areas, we highly recommend that the game-based learning community investigate ways in which they may develop consistent definitions for game- and simulation-related interventions.
2. *Create an educational video game repository*. Many games in mathematics and science were special purpose implementations of game mechanics for particular school content. Only a handful of research articles have provided in-depth descriptions of the game mechanics and algorithms utilized in their studies, making it difficult for experimental follow-up and replication. To rectify this shortcoming, we recommend the compilation of a game database intended to store copies of all non–commercially available researched games such that other researchers may replicate experimental designs to cross-check validity and further develop and test hypotheses about particular game attributes. On the creation of such a tool, games could be metatagged for their curricular objectives and operative game mechanics. This database would also greatly expedite the construction of new software, given that open-source programs could be modified for varied content areas without the devotion of resources to recoding all necessary video game components.
3. *Research educational video games already in use*. Because many educators already utilize video games in their day-to-day instruction, there is ample opportunity for researchers to conduct action research on in vivo classroom data. However, the number of articles taking advantage of these regular classroom activities is small. We believe that more concerted efforts toward making “two-inch putts” from the current application of educational video games to publishing information about their results would go far in furthering

the total sum of how video games affect student performance in school achievement, engagement, behavior, motivation, and other areas of interest.

4. *Conduct longitudinal studies that examine the impact of educational video games*. In our review of the literature, we found no studies or projects that examined the long-term effects of game-based learning. The longest implementation we reviewed was 10 weeks, whereas outside of school, game play often continues for years. Although such research is typically difficult to conduct and requires a larger participant pool than can be derived from a single classroom, we believe that a plethora of relevant data could come from establishing trends for gaming and learning beyond the few week- or month-long interventions currently available. With whole-school curricula being enhanced with games, such as in Quest2Learn and Quest Chicago, it has become possible to consider longitudinal research. This type of research will be particularly useful in looking at student motivation to learn subject area content, especially with funding from large governmental and private grants toward STEM and physical education. Such research would be extremely helpful to the educational community in generating insight into modifications that need to be adopted to prompt long-term student behavioral and attitudinal changes.
5. *Encourage collaborative partnerships among commercial game companies, educational researchers, teachers, administrators, policymakers, and parents.* Commercial games such as Blizzard Entertainment's *WoW* have far greater resources and player population pools than any individual research institution studying the academic application of self-constructed learning games. Yet the commercial success of games often means an intentional distancing from traditional school content for fear that the combination might reduce entertainment appeal. This is an issue that only educational research can pursue since it is unlikely commercial game companies will risk manipulating their game content for research purposes.

   We believe that commercial gaming companies and educational researchers could mutually benefit by bringing academic content into the fictitious worlds originally created without educational content objectives in mind. Rather than attempting to reframe academic objectives in their own immersive universes, educative minigames could be added to larger game worlds to meet both the learning objectives of a subject area course and the narrative of the game. For example, our group discussed how *WoW*'s alchemy profession could be slightly modified such that the creation of potions would rely on a basic understanding of physical chemistry, thereby providing information that would be both useful within the context of the game's parameters and transferable to conducting chemical experiments in the real world. This innovation would invariably provide additional learning opportunities as players begin to share their knowledge with one another and participate in cognitive apprenticeships between accomplished alchemists and novices, fostering a more science-educated community within the player community as well as possibly adding another element of fun.

6. *Include the metagame*. Ensure that game play is not the sole instructional strategy nor the sole focus of research interventions. Much of the "learning"

of video game play may come from affinity groups that emerge from game play, consisting of metagame sources such as blogs, wikis, and discussion pages that support hints, cheats, and modding. If this perspective holds true, then research that concentrates solely on the game as initially designed or game mechanics may be searching in the wrong castle. If learning outside the game can be as powerful as learning directly from game play, then educational research must begin to determine the role of social learning and discover how metagame learning as well as game play can be exploited for instructional goals.

Our findings indicate that educational video games are most frequently researched as the primary means by which the player learns, removing the instructor and allowing the student to complete his or her learning in isolation. However, just as students are not given books and told to learn independently, games cannot succeed as stand-alone solutions to education; there must be a facilitator present to guide learning and ensure (a) that the information being taught is indeed generalizable outside the context of the game and (b) that deeper, metacognitive gains are attained as a result of socially constructed game play. We recommend combining pedagogical methods to better gather data regarding the effectiveness of video games as teaching tools and examining how gaming combined with instructional facilitation by a master teacher affects engagement, student behavior, and overall academic achievement.

7. *Work toward assessments that make it possible to understand the relationships among players, their social interactions with one another, their games, and their metacognitive reflections*. Ideally, testing in the field of game-based learning research should utilize log files to establish complex connections between players and the virtual environment. Such log files frequently exist for commercial server-based games but are not accessible to researchers. Data visualization techniques, graph theoretic techniques, and modeling strategies should be leveraged to understand how gaming unfolds across time and (virtual) space as a rich, dynamic, player–environment interaction on several levels. Assessments should be situated in the games under evaluation and should facilitate game play, not simply allow individuals to render postplay judgments. This change will allow researchers to develop individualized materials that provide constructive feedback along multiple behavioral and cognitive strands for each student–player. Although the general linear model and classical test score theory that underlie many data analyses may be helpful in finding trends across large groups, the individualized information that could be derived from situated gaming-learning experiences extends far beyond what any single analytical technique may capture, especially in learning-rich massively multiplayer gaming environments.
8. *Ensure that game objectives and learning objectives correspond*. For games used in schools, the alignment of game goals and instructional goals can reduce the barriers student–players encounter as they make progress toward their academic goals. Considering cognitive workload, overly complex

game mechanics can compete with curricular elements for attention, resulting in a greater number of misconceptions or interference with students' ability to develop conceptual understanding. A consistent 1:1 ratio of gaming and learning objectives would resolve many of the underlying structural problems that may inhibit learning from educational video games.

9. *Stop seeking simple answers that address the wrong question*. What may seem like missing information may in fact point to a misdirection in our original question: Do video games enhance academic achievement? Our first recommendation (above) calling for a shared working definition suggests that video games vary widely in their design and related educational affordances: Some have elaborate and engaging backstories, some require problem solving to complete 5 to 40 multiplayer quests, and some rely heavily on fine motor controller skills. With this range of attributes, perhaps no single experimental manipulation (independent variable) can ever be defined to encompass the concept of video games writ large. Furthermore, given the diversity of student learning goals and abilities, likewise perhaps no singular outcome (dependent variable) from video games should be anticipated.

Instead, applying principles from situated cognition suggests that research should focus on the complex interaction of player–game–context and ask the question, "How does a particular video game being used by a particular student in the context of a particular course curriculum affect the learning process as well as the products of school (such as test grades, course selection, retention, and interest)?" No research of this type was identified in our review, suggesting the missing element may be a more sophisticated approach to understanding learning and game play in the rich contexts of home and school learning.

Conclusion

We believe that by improving the way that we collectively examine video games as learning and instructional tools, the educational community will be able to craft much stronger, well-founded games that go further in improving the student experience than the studies examined for the purposes of this review. Studies in language learning, and to some degree PE, point to very promising impacts that video gaming can have on school achievement. The technological world is rapidly advancing, and there is an obligation on educational researchers to ensure that we are making all of the necessary accommodations to assist one another in more accurately and succinctly defining the affordances embedded within video games.

We suggest a partnership among teachers and schools experimenting with games in their classrooms, alongside educational researchers familiar with contemporary learning theory, game players willing to endure sometimes invasive data collection procedures, and educational stakeholders interested in exploring games for improving how learning and instruction take place in school. Isolating the pedagogical affordances of particular game mechanics can help further the designs of mathematics and science learning games and clarify the mixed results in the current literature.

In closing, let us prepare our blue overalls and plungers as we embark on the next journey through the warp pipe to find the right princess in the right castle, taking advantage of the opportunities offered in the burgeoning field of game-based learning, and steering our inquiry in a direction that will prevent us from becoming stuck on challenges we need not undertake, eventually producing the highest score: engaging and effective student learning.

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