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Educational Video Game Design: A Review of the Literature

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Abstract

Much attention has been directed to the use of video games for learning in recent years, in part due to the staggering amounts of capital spent on games in the entertainment industry, but also because of their ability to captivate player attention and hold it for lengthy periods of time as players learn to master game complexities and accomplish objectives. This review of the literature on video game research focuses on publications analyzing educational game design, namely those that present design elements conducive to learning, the theoretical underpinnings of game design, and learning outcomes from video game play.

Introduction

Many articles have been published in the last 20 years on video games for learning, and several reviews of the literature on educational games have been completed within the last few years (Aguilera & Mendiz, 2003; O'Neil, Wainess, & Baker, 2005). However, these reviews focused on literature that addressed what players learn from video games rather than how video games can be designed to facilitate learning. This review focuses on publications addressing educational video game design, seeking to identify elements of game design that promote learning as well as the learning theories that conceptualize how video games foster learning.

Research Focus and Search Methods

A multiple database search using the search terms *game design* AND *video* or *computer* or *PC* AND *educational* or *instructional*, yielded nearly 100 publications from the following databases:

- Academic Search Premier
- ACM Digital Library
- Communication and Mass Media Complete
- Computer Source
- ERIC
- Information Science and Technology Abstracts
- Internet and Personal Computing Abstracts
- Library, Information Science, and Technology Abstracts
- PsychARTICLES
- Psychology and Behavioral Sciences Collection
- PsychINFO
- Science and Technology Collection
- Social Sciences Abstracts

Search results were further limited to include only peer-reviewed journal articles, conference proceedings, and frequently cited books, criteria which culled the list to 56. Closer review of these publications revealed that several did not address issues related to game design. The resulting list contained 35 items spanning the last ten years, most of which were published in the last three (30 of 35 items). Results were not narrowed by specific game types, nor were design studies on game-like environments excluded as they apply design elements from video games to environments for learning and are consequently relevant to this review. Game-like environments included augmented and virtual reality, multi-user virtual environments, interactive learning environments, simulations, and simulation games.

The publications reviewed are organized loosely into those that address characteristics of educational games, elements of effective video game design, learning theories for video games, learning outcomes from game play, and gender preferences in video game design. These categories provide an organizational framework for understanding significant design considerations revealed in the literature. Nevertheless, most of the publications reviewed do not fit neatly into a single category. Many of the studies contain findings that are relevant to several of the categories employed here, but may be reviewed fully only once and simply cited where otherwise appropriate.

Elements of Effective Video Game Design

Edutainment vs. Educational Games

It is important to distinguish between educational and edutainment games prior to proceeding with a review focused on educational video game design. According to Denis and Jouvelot (2005), "The main characteristic that differentiates edutainment and video games is interactivity, because, the former being grounded on didactical and linear progressions, no place is left to wandering and alternatives" (p. 464). Edutainment games, then, are those which follow a *skill and drill* format in which players either practice repetitive skills or rehearse memorized facts. As such, "Edutainment often fails in transmitting non trivial (or previously assimilated) knowledge, calling again and again the same action patterns and not throwing the learning curve into relief" (Denis & Jouvelot, 2005, p. 464). In contrast, educational video games require strategizing, hypothesis testing, or problem-solving, usually with higher order thinking rather than rote memorization or simple comprehension. Characteristics of such games include a system of rewards and goals which motivate players, a narrative context which situates activity and establishes rules of engagement, learning content that is relevant to the narrative plot, and interactive cues that prompt learning and provide feedback.

Nevertheless, even skill and drill games that employ such characteristics have demonstrated gains in learning. Lee, Luchini, Michael, Norris, and Soloway (2004) found that a math facts game for second graders deployed on handheld computers encouraged learners to complete a greater number of problems at an increased degree of difficulty. Learners playing the handheld game completed nearly three times the number of problems in 19 days as those using paper worksheets. Learners using the handheld game also voluntarily increased the level of difficulty in the game as they continued to play.

Motivation

Several publications examine motivation in video games. However, not all researchers entirely agree on the source of this motivation. Some attribute the compelling nature of games to their narrative context (Dickey, 2005, 2006; Fisch, 2005; Waraich, 2004) while others find motivation is linked to goals and rewards within the game itself or intrinsic to the act of playing (Amory, Naicker, Vincent, & Adams, 1999; Denis & Jouvelot, 2005; Jennings, 2001). Nevertheless, all find that motivation to play is a significant characteristic of educational

video games and that effective game design considers both intrinsic and extrinsic rewards for play. Denis and Jouvelot (2005) distinguished between the two and their absence as follows: "Intrinsic motivation pushes us to act freely, on our own, for the sake of it; extrinsic motivation pulls us to act due to factors that are external to the activity itself, like reward or threat; amotivation denotes the absence of motivation." (p. 462) These authors see motivation as the interplay between desire and pleasure—the desire to be competent and the pleasure one feels when one is. They argue that competence, autonomy, and relatedness are factors that affect motivation. "Motivation also leads to the activation of efficient cognitive strategies for long-term memory issues like monitoring, elaborating or organizing information. On the opposite side, resignation and amotivation have negative results on memorization and personal development" (p. 463).

Amory, Naicker, Vincent, & Adams (1999) examined four different game types and analyzed elements that players liked most. In this study, students rated a number of game qualities including "the fun aspect, sounds and graphics, type of game, game story and use of technology"; "the importance of some skills [logic, memory, visualisation, and mathematics, reflexes, and problem solving]"; "whether the game was easy to play, addictive, too long, challenging, confusing, too difficult, illogical, difficult to play or manoeuvre and if their performance increased with continuous play" (p. 314). Adventure and strategy games were found to be the most stimulating and rated the highest, a finding which suggests that players preferred or were more motivated to play games with objectives requiring higher order thinking skills, including visualization strategies that nurture creative problem solving and decision-making. (p. 317).

On a similar note, Dickey (2006) argued that a narrative context that promotes "challenge, fantasy, and curiosity" and provides feedback for players is one that promotes intrinsic motivation for play (p. 2). She also finds that, "Strategies of design that lead to engagement may include role-playing, narrative arcs, challenges, and interactive choices within the game as well as interaction with other players" (p. 1). In another study, Waraich (2004) agreed narrative is essential to motivation but cautioned that, "intrinsic rewards are based on a high congruence between the material being taught and the motivational techniques used" (p. 98). Dissonance between the two can decrease learning.

Narrative Context

Disagreement on the source of motivation aside, a general consensus that narrative context is an important element of effective video game design does exist. Five articles in this survey supported this finding and dealt most prominently with narrative as a significant design element. In two studies on game-like environments for learning, Dickey (2006) found that 3-D learning environments not only provide a narrative context for situating and contextualizing learning, they also enable spatial relationships rather than linear ones. In an article on the design of Murder on Grimm Isle, a game created to cultivate argumentative writing skills, Dickey concluded spatial and narrative contexts offer learners, "a cognitive framework for problem-solving because the narrative storyline in games provides an environment in which players can identify and construct causal patterns which integrates what is known (backstory, environment, rules, etc.) with that which is conjectural yet plausible within the context of the story" (p. 2).

In another article, Dickey (2005) presented similar findings in case studies of two 3-D environments for courses in business computing and 3-D modeling, arguing that contextual elements such as a first person symbolic perspective and 3-D representations of space increase learners' sense of presence and consequently their interaction and collaboration. "This [narrative] context builds on learners' real-world knowledge by providing a visual metaphor, or perhaps more aptly stated, a visual narrative of the course content" (p. 444).

In a study of a variety of design elements on game environments for instruction in computer science architecture, Waraich (2004) focused mainly on narrative. This empirical study analyzed the role of both narrative context and game goals as features for motivating and conceptualizing learning in a 2-D interactive learning environment (ILE). The mixed methods design of the study revealed quantifiable knowledge gains in the ILE over traditional instruction. Waraich concluded that, "For any learning task to be meaningful to the learner they must have both a sufficient context for the learning and motivation to perform the tasks that will help them to learn. We believe that game based learning environments that incorporate a strong narrative can meet these requirements if the learning tasks are appropriately designed and tightly coupled with the narrative" (p. 98).

In what is largely a theoretical discussion more so than a research study, Fisch (2005) made a similar observation. Although narrative context does motivate learning, for an educational game to be effective the learning content must align with the narrative plotline. According to Fisch's analysis, "research on lectures and textbook readings has suggested that seductive details do not work; children exposed to such material tend to remember the appealing elements but not the intended educational content" (p. 57). He found that a "far more powerful approach is to place the educational content at the heart of engaging game play, so that children employ the targeted academic skills and knowledge as an integral part of playing the game" (p.58). Fisch also maintained that selecting appropriate media as well as providing feedback and scaffolding within and outside of the game are essential to effective educational game design.

Goals and Rules

Another significant element of effective video game design is a system of objectives, goals, and rules of play (Waraich, 2004; Zagal, Nussbaum, & Rosas, 2000). Although they are integrated within a narrative context, goals and rules are not subordinate to context; they are equally important elements of it. In an overview of initiatives in educational games, Jenkins, Klopfer, Squire, and Tan (2003) described the design and testing of three video game prototypes: Supercharged!, a game on electromagnetism; Environmental Detectives, an environmental science game; and Revolution, a game for American history. Each has a narrative structure that students follow to determine their objectives or goals. Players take the role of a charged particle in Supercharged!; a scientist in Environmental Detectives; and a soldier, revolutionary, or townsperson in Revolution. Each game has distinct objectives and a variety of rules frame the play. Players must master the rules of the game to accomplish the objectives. For example, the laws of electromagnetism provide the rules in Supercharged!

Swartout and van Lent (2003) further elaborated on goals in effective video games, finding that goals of different levels help motivate learners to continue playing. "Game designers often seek to keep players engaged by creating three levels of goals: short-term (collect the magic keys), lasting, perhaps, seconds; medium-term (open the enchanted safe), lasting minutes; and finally, long-term (save the world), lasting the length of the game" and that the "interplay of these levels, with the support of the environment, is crafted to draw players into the storyline of the game" (p.34). This design concept is similar to Gee's (2003) "Achievement Principle" which states that, "for learners of all levels of skill there are instrinsic rewards from the beginning, customized to each learner's level, effort, and growing mastery and signaling the learner's ongoing achievement" (p. 67).

Interactivity and Multisensory Cues

Interaction between the player (or players) and the game environment is another element embedded in the narrative context and game objectives. Effective games weave objects and characters into a game environment that provide feedback and hint structures for successful game play (Fisch, 2005). Moreover, the

degree of user control over the game environment further constitutes the level of interactivity. Swartout and van Lent (2003) deemed that the best games are "highly interactive, deliberately generating tension between the degree of control the story imposes and the player's freedom of interaction" (p. 34), reasoning that in games with complete freedom of interaction, the playing experience can be boring and unchallenging. On the other hand, when the plotline imposes too much control, the player becomes a passive observer rather than an active participant. Providing a balance to these extremes, effective game design gives players, "the perception they have free will, even though at any time their options are actually quite limited" (p. 34). Gee (2003) called this concept the "Regime of Competence" Principle, which states the player/learner is challenged at the edge of his or her abilities.

In an overview of the design process and the various elements of multiplayer games, Zagal, Nussbaum, and Rosas (2000) examined the role of interactivity as a critical element in effective games, proposing that game designers should consider the extent to which the game rules, props, and tools affect stimulated and natural social interaction. Such interactions might depend on cooperation, competition, or a combination of both. They might also require synchronicity or coordination, types of interactions which are determined by player composition in the game. The article included a model for analyzing player composition and social interaction in game design.

Quax, Jehaes, Jorissen, and Lamotte (2003) described the design of a game that allowed users to stream video of their facial expressions to specific regions within a multi-user virtual environment. They found that segmenting the game world so that video is streamed only to the regions occupied by the player uses less bandwidth. The significance of this study for game design is the finding that visual cues afforded by streaming video provided nonverbal communication which increased player immersion and collaboration with others in the environment.

A study by Salzman, Loftin, Dede, and McGlynn (1996) further confirmed that multisensory cues are a significant component of successful game-like environments. The researchers concluded that, "Multisensory cues can engage learners, direct their attention to important behaviors and relationships, help them understand new sensory perspectives, prevent errors through feedback cues, and enhance ease of use" (p. 2). While learning outcomes afforded by gaming media will be discussed in greater depth later in this review, another significant finding in this study is that multisensory interactions "can help learners understand complex phenomena," particularly for students with "severely limited or inaccurate mental models of science concepts" (p. 2).

Learning Theories for Video Games

Constructivism

Several researchers previously cited found that learning with well-designed video games adheres to constructivist principles (Dede, Nelson, Ketelhut, Clarke, & Bowman, 2004; Dickey, 2005, 2006; Gee, 2003; Schrier, 2006). In an article describing the multi-user virtual world, SciCtr, Corbit (2005) underscored the merits of a constructivist approach for analyzing game-like environments. In SciCtr, students create virtual science worlds, such as rainforests or deserts, that other learners can visit and explore. According to Corbit, these worlds, the paths to navigate through them, and content embedded in them, are constructed by the developer/learner through meticulous research and thoughtful design.

Constructionism

Designing and developing video games, rather than playing them, applies a contructionist approach to learning with games (Robertson & Good, 2005; Robertson et al., 2004). El-Nasr and Smith (2006) viewed game

modding—the development of new modules in an existing game using toolkits packaged with the game—as a constructionist method of learning. The constructionist approach to learning involves two activities: the construction of knowledge through experience and the creation of personally relevant products. The theory proposes that whatever the product, be it a birdhouse, computer program, or robot, the, "design and implementation of products are meaningful to those creating them and that learning becomes active and self-directed through the construction of artifacts" (p. 2).

Steiner, Kaplan, & Moulthrop (2006) concurred with this constructivist view and contended that, "children as design partners improve the technologies they consume as well as gain educational benefits from the experience" (p. 137). Burrow and More (2005) applied constructionist techniques in an architecture course by having students render their designs with a game-engine thereby exploring spatial relationships as well as atmosphere, lighting, and other environmental conditions in a 3-D simulation of their architectural designs.

Situated Cognition

In a symposium on learning theories for the analysis of educational video games, Halverson, Shaffer, Squire, and Steinkuehler (2006) asserted that situated cognition provides a meaningful framework for the study of games, given that games have an ability to situate learning in an authentic context and engage players in a community of practice. Dede, Nelson, Ketelhut, Clarke, and Bowman (2004) outlined both constructivist and situated learning design principles present in effective video games including GST (guided social constructivist design), EMC (expert modeling and coaching) and LPP (legitimate peripheral participation). These authors employed such principles in evaluating game design and applied their findings to future iterations of the design. Lunce (2006) also argued that situated or contextual learning provides the rationale for simulations and simulation games in a classroom environment because of their ability to provide an authentic context in which to situate learning. According to these and other scholars, the authentic, situated context affords greater content mastery and transfer of knowledge than a traditional classroom learning (Dickey, 2005, 2006; Klopfer & Yoon, 2005; Schrier, 2006).

Learning Outcomes from Educational Video Games

21st Century Skills

In a historical review of the research on video game design, Aguilera and Mendiz (2003) maintained that, "arguments in favor of the cognitive importance of video games are based on a number of studies indicating that many video games are conducive to the development of specific skills: attention, spatial concentration, problem-solving, decision-making, collaborative work, creativity, and, of course, ICT skills" (p. 8). Many of these skills are earmarked as necessary to successfully participate in the global, knowledge based economy of the 21st Century. Employing cursory case studies of specific games and anecdotal comments from young video game players as evidence of his assertions, Prensky (2006) contrasted the nature of digital immigrants (those who have recently migrated to the use of digital technology) to that of digital natives (those who have grown up with it). Although Prensky is not an educational researcher, he is a widely acclaimed speaker and writer on how complex video games teach digital natives in ways not offered by traditional instruction. The most significant of his ideas include his description of complex videos games and the 21st Century skills that game play can impart.

Schrier (2006) designed an augmented reality game designed specifically to foster modern skills. The research design employed a mixed-methods approach which included pre- and post attitudinal surveys, interviews, and video taped learning sessions. These efforts yielded results which suggest that problem-based

learning augmented with game-like design features can indeed encourage the development of modern skills. Since Schrier's research did not employ an experimental design comparing the augmented reality treatment to a control group, generalizations about learning gains in the game-like environment over a traditional classroom were not supported by the study.

Deduction and Hypothesis Testing

The results of a variety of studies suggest that video games and game-like environments are conducive to deductive reasoning and hypothesis testing (Aguilera & Mendiz, 2003; Gee, 2003; Jenkins et al., 2003; Klopfer & Yoon, 2005; Lunce, 2006; Salzman, Dede, & Loftin, 1999; Salzman et al., 1996). In a qualitative analysis of both what and how students learned playing Civilization III in an interdisciplinary history, humanities, and social studies course, Squire and Barab (2004) found that game play promoted deep learning, hypothesis testing, strategizing, and appropriating content (history, in this case) as a tool for play. Squire, Barnett, Grant and Higginbotham (2004) established that students in an experimental group who played the simulation-game Supercharged! better mastered the abstract and conceptual knowledge related to electromagnetism than those in the control group who learned through guided discovery-based science methods. The researchers attributed these learning gains to replay for testing new hypotheses afforded by the simulation game.

Complex Concepts and Abstract Thinking

Other studies concurred with the findings of Squire, Barnett, Grant, and Higginbotham (2004) concerning mastery of abstract and conceptual knowledge through game play (Aguilera & Mendiz, 2003; Gee, 2003; Lunce, 2006; Prensky, 2006). Writing about technology in general rather than games specifically, Kelly (2005) argued that technology applications including video games promote mastery of complex concepts. In a qualitative case study of the game-like computer-modeling environment, StarLogo, Klopfer and Yoon (2005) discovered that struggling students were able to better comprehend complex systems after working with StarLogo.

Visual and Spatial Processing

Because most complex video games are situated in 2- or 3-D environments, it is no surprise that research has found increased spatial development in video game players. According to Aguilera and Mendiz (2003), "adolescents with medium- or long-term experience playing video games show greater visual capacity, motor activity, and spatial abilities-reflexes and responses" (p. 6). Using game engines to render and then explore the effects of architectural designs, Burrow and More (2005) observed that the capabilities of game-engines "allow participants to experience the spatial design in ways that are not predetermined by the designer" (p. 35). The objective of the Burrow and More project was to explore the relationship between architectural design elements and atmosphere, analyzing both the atmosphere produced by the architectural design and the impact of atmosphere on the design. Burrow and More argued that this focus "emphasizes critical thinking on the nature of space and its representation … and its interactivity" (p. 38).

Gender Preferences in Video Game Design

Studies on the gaming habits of girls present rather mixed results. While it is widely presumed that girls do not play video games with the same intensity or for durations as lengthy as boys do, empirical research finds little evidence to support this supposition. In a study that observed the gaming preferences of girls in a games club at an all-girl state school in the United Kingdom, Carr (2005) observed that girls played games they were

exposed to and knew about, regardless of genre or avatar gender. As a result, she concluded that preferences have little to do with gender or gendered game types and more to do with access and prior gaming experience. To the extent that games and certain game genres are marketed to males, girls may have little knowledge of their attributes. But, once exposed to conventionally "male" games, girls played them aggressively and seemed to enjoy the games.

In the development of an evolution game targeting girls, Heeter, Winn, and Green (2005) developed and play tested 50 iterations of the game. Results throughout the process indicated that failed iterations were due to poor game design rather than inadequate attention to gender preferences. Nevertheless, play testing throughout the process did produce findings about the play habits of girls, namely that girls consistently play significantly slower than boys. However, additional data on the play habits of both sexes need to be collected to validate generalizations about gender differences in play habits.

In a study aimed at determining whether girls differ from boys in visual cognition, Ziemek (2006) concluded that females are less spatially dexterous than males. Girls prefer to use a wider view (more of an overview) than most 3D games provide. The study indicates that girls struggled with camera angles in 3D games and preferred the closed view of a 2D environment. However, given the relatively small sample size (34 subjects; 19 girls) the results may not be conclusive or broadly generalizable. Nevertheless, the results point to a need for further investigation.

Conclusion

It is fairly clear from the breadth of research on the subject, that video games do affect learning. While there is widespread consensus that games motivate players to spend time on task mastering the skills a game imparts, some disagreement over the specific characteristics that provoke that motivation exists. Nevertheless, the literature reveals that a number of distinct design elements, such as narrative context, rules, goals, rewards, multisensory cues, and interactivity, seem necessary to stimulate desired learning outcomes. Moreover, researchers are beginning to theorize the cognitive processes that occur through video game play. As these inquiries progress, a better understanding of educational game design and the production of improved educational games will ensue. In turn, design and development will likely generate further research on the learning outcomes afforded by educational game play, including those affected by gender preferences.

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