ABSTRACT—Recently, there has been a great deal of interest in the use of video games for education because of the high level of engagement of players. This article blends research on game engagement from the media flow perspective with current pedagogical theory to advance two core design principles for a model educational game design: model matching and layering.

KEYWORDS—educational media; video games; strategic thinking; cognitive skills; flow; mass communication

Scholars from several disciplines have convincingly advocated the merits of video games as a pedagogical tool (e.g., Gee, 2007; Greenfield, 2009; Ritterfeld, Cody, & Vorderer, 2009; Squire & Jenkins, 2004). We present one approach to thinking about human–game interaction research and educational game design. For many children, enjoyment in video game play results from the challenge of learning the rules and affordances (qualities such as the ability to fly, jump, etc., that allow a player to engage in actions) of a game’s world (Sherry, Lucas, Greenberg, & Lachlan, 2006), because taking on game challenges can result in a highly rewarding mental state known as “flow” (Sherry, 2004; Weber, Tamborini, Kantor, & Westcott-Baker, 2009). Thus, a prime opportunity for engaged learning exists in the core mechanism for game enjoyment: challenge. If designers were to place formal educational content (e.g., cell physiology rules and affordances) in a game world as the challenge, players would be more likely to experience flow and master the content.

HOW DO GAMERS CONSTRUE GAMES?

Research has shown that the most popular motivation for video game play is the challenge of solving cognitive puzzles (Raney, Smith, & Baker, 2006; Sherry, Lucas, et al., 2006; Vorderer, Hartmann, & Klimmt, 2003). Of the six video game uses and gratifications that Sherry, Lucas, et al. (2006) developed in focus groups and surveys, challenge was the top reason for playing video games among the college students, eleventh graders, and fifth graders. Participants stated that they play to experience the mastery of overcoming a difficult level and to push themselves to beat the game. Games allow players to experience mastery through cognitive effort (Grodal, 2000).

Game challenges consist of numerous obstacles and hindrances to achieving the game’s preordained goal. Although challenges may appear potentially frustrating, engaging the challenges can result in a highly pleasurable altered state that Csikszentmihalyi (1990) first labeled “flow.” Individuals in a flow state experience highly focused concentration leading to a loss of time and self-awareness, a sense of seamless control between thought and action, and an intrinsic reward for play. Media flow theory (Sherry, 2004) asserts that flow is achievable if the demands of a particular media product (such as a video game) are at or slightly beyond the ability of the user. While in the flow state, players experience a profound sense of accomplishment in defeating the game’s obstacles, as well as neurophysiological rewards resulting from intensely focused attention, particularly striatal opioid peptide release resulting in pleasurable feelings of reward (Weber, Tamborini, Kantor, & Westcott-Baker, 2009).

Challenges in games appear in either manifest or intrinsic form. Manifest challenges are the obvious enemies or tasks that the player must overcome to win. For example, in a typical action–adventure game, the player must beat a series of enemies to traverse a series of worlds. Intrinsic challenges involve the necessity of learning the unique allowances, limits, rules, and strategy of a particular game. This learning allows the player control over the game environment (its “world”) and characters...
to adequately navigate and interact in the game world. In order to overcome the manifest challenge, the gamer must first master the intrinsic challenges. To master the intrinsic challenges, the gamer must create a mental model of the intrinsic obstacles in the game world that is similar or identical to the true computer game model. This learning is highly active, complex, and learner centered (Gee, 2007). Taking up the intrinsic challenges of the game is most likely to result in the flow state (Sherry, 2004). This provides the first core design principle from media flow theory:

Core Design Principle 1: Because game-related learning is targeted at intrinsic challenges, educational content should be part of the intrinsic challenges of the game.

Successful play requires that players have a variety of skills to master intrinsic challenges. These consist of game-related abilities that facilitate interaction with and interpretation of the game environment. We can divide these skills into three key areas (there may be others); kinetic learning and skills to operate the interface (e.g., eye–hand coordination to work controllers), strategic thinking ability to solve complex puzzles (e.g., resource allocation, planning, scientific method), and a variety of cognitive skills that facilitate interaction with the game world (e.g., three-dimensional mental rotation, targeting). When game play demands skills that are sufficient to meet its challenges, gamers are likely to enter into a highly pleasurable flow state. Research suggests that game play can enhance these skills. Hence,

Core Design Principle 2: A well-designed game teaches more than content; games should contain opportunities for kinetic, work habit, strategic, and cognitive skill learning.

**CORE DESIGN PRINCIPLE 1: CREATE MENTAL MODELS**

Experienced game players know that they must explore and test the game world in order to achieve manifest goals such as beating a level or ultimately winning the game (Yee, 2006). The process of learning the game environment is a process of creating a mental model of the game that is similar or identical to the programmed computer model of the game. Researchers in fields as varied as developmental psychology (e.g., Flavell, 1996; Piaget, 1985), cognitive psychology (e.g., Barrouillet & Grosset, 2007; Johnson-Laird, 1983), communication science (e.g., Roskos-Ewoldsen, Roskos-Ewoldsen, & Dillman Carpentier, 2002), and educational research (Anderson, Spiro, & Montague, 1977) agree that people create mental models as shorthand for understanding human experience. Roskos-Ewoldsen et al. (2002) defined mental models as “a cognitive representation of situations in real or imaginary worlds (including space and time), the entities found in the situation (and the states those entities are in), the interrelationships between the various entities and the situation (including causality and intentionality), and events that occur in that situation” (p. 223). Entities are discrete objects or concepts that are distinct from one another via any number of characteristics and are relationally structured via three things: (a) shared characteristics that are called causal relationships, (b) the spatial information connecting entities, and (c) costs of alternative outcomes of entities in given relationships (Handley & Feeney, 2007). A causal relationship occurs when there is a “relationship between the occurrence of some variation of one variable . . . and the occurrence of variations of another variable . . . in the same setting” (Crano & Brewer, 2002, p. 178). Spatial information is the location status and measurement of distance from one entity to another. The costs of alternative outcomes refer to an evaluation of what conditions might exist if the conditions in the current state were different.

Similarly, game models are the structure of the relationships among discrete elements, called “game mechanics,” that make up the play of a given game (e.g., Bates, 2004; Bethke, 2003; Bjork, Lundgren, & Holopainen, 2003; Clanton, 1998; Salen & Zimmerman, 2004; Sellers, 2006; Squire, Barnett, Grant, & Higginbotham, 2004). Loosely, game mechanics refers to game rules, game environmental conditions, and allowable player actions in pursuit of play, or the parameters that enable the player to engage the specific challenges that digital games provide (Eigen & Winkler, 1981; Salen & Zimmerman, 2004). Categories of game mechanics include the physical properties imposed on the structure of the virtual world, as well as the actions that a player can cause the character or avatar to take. These actions are most often related to character movement, vulnerability to threat, sense knowledge, and interaction (e.g., speaking, shooting, fighting). Each of these character mechanics has parameters that delimit a particular ability. Similar to mental models, game mechanics are related to each other through causal relationships, spatial information connecting entities, and costs of alternative outcomes of entities in given relationships.

As players interact with the game, they create a mental model that accounts for the game’s intrinsic challenges in order to overcome the manifest challenges. They use a trial and error process, comparable to the scientific method, to hone their mental model of the programmed game model rules. Experienced players enter a new game space assuming that they must learn the rules of the environment and the ways of interacting and that failure is inevitable for ultimate progress. As players test the limits of the world and the character, they must figure out how to optimize resources that provide the ability to overcome manifest obstacles. To do so, experienced gamers will form a theory (e.g., “the physics of the game world are similar to those of the real world”) and test the theory to failure. Because testing to failure is so important to game play, most games are designed with multiple player “lives” (sic) and the ability to play the game over and over until achieving mastery.
Progress through game stages requires that players understand increasingly complex game elements. However, the learned mechanics of a game rarely change from level to level. Instead, players build on obtained knowledge in their quest to master more difficult obstacles. In the educational literature, building new understanding based on prior knowledge is known as “scaffolding” (Bransford, Brown, & Cocking, 1999).

The model-matching process provides a point of entry for using video games as an educational tool. Intrinsic challenges engage and reward players, making the games appealing. If the intrinsic challenges in the game model contain the educational content it is trying to teach, the process of normal game play becomes an engaging process of creating a mental model of the educational content via the game model. For example, a game might model the complex, dynamic relationships among entities (organelles) in a cell. To complete the manifest challenge, the player would need to learn the abilities of the organelles and how they relate to each other. Because the process of model matching is cognitively active, relies on prior building knowledge, requires reflection on possible strategies to solve the game, and uses a common model across a number of different levels, designers can effectively build modern pedagogical practices such as active learning, scaffolding, metacognition, and transfer into the game-playing process (Gee, 2007). In fact, programmers already use principles of learning in many commercial entertainment video games to foster expedient and efficient learning of game mechanics (Gee, 2007; Schaffer, 2006). It is not clear from research whether the game content would need to be blatant (e.g., “The Cell Game”) or if it would be possible to model the entities and relationships in a game with a different theme (e.g., “The Dating Game” or “The Car Driving Game”), then transfer them to biological knowledge, perhaps by the teacher.

**DESIGN PRINCIPLE 2: TEACH MORE THAN CONTENT**

When they approached the challenge of designing educational television programming, the researchers at the Children’s Television Workshop learned that they could layer multiple types of educational outcomes within a single program segment (Lesser, 1974). For example, a Sesame Street segment in which Bert and Ernie argue over bottle caps could feature symbolic processes (counting bottle caps), cognitive organization (sorting them according to color), and social self (illustrating how to resolve conflict). Intrinsic challenges of games provide the possibility of a variety of additional types of learning. Research has emerged showing that games can aid learning in several areas: kinesthetic learning and skills to operate the interface (e.g., eye–hand coordination to work controllers), strategic thinking ability to solve complex puzzles (e.g., resource allocation, planning, scientific method), and a variety of cognitive skills that facilitate interaction with the game world (e.g., three-dimensional mental rotation, targeting, etc.).

**Kinesthetic Skills**

A number of studies have demonstrated that video game play can assist in the development of kinesthetic skills, such as eye–hand coordination. Griffith, Voloschin, Gibb, and Bailey (1983) found that gamers had superior eye–hand coordination to non-gamers, although amount of time spent playing games did not appear to matter. Similarly, another cross-sectional study (Rosser et al., 2007) indicated that surgeons who are experienced gamers have significantly better laparoscopic surgical skills. Experiments manipulating video game training have supported this finding (Rosenberg, Landsittel, & Averch, 2005; Schlickum, Hedman, Enochsson, Kjellin, & Fellander-Tsai, 2009). These findings confirm an earlier study (Gagnon, 1985) that found that video game practice increased eye–hand coordination, particularly for female subjects.

**Strategic Thinking**

A number of studies have demonstrated that video games effect strategic thinking (Blumberg & Ismailer, 2009). Blumberg, Rosenthal, and Randall (2008) found that game players use a variety of strategies for negotiating game challenges. Importantly, they found that gamers’ focus shifted from content features (e.g., game mechanics, background knowledge) to strategic features (e.g., impasse recognition, insight) as playtime continued. This finding is consistent with basic game design rules that advise introducing minimal challenges at the beginning and building difficulty in complexity as the game proceeds. In one series of experiments, Paredes-Olay, Abad, Gamez, and Rosas (2002) tested whether strategies taught to gamers prior to play would transfer to actual game play situations. Their college-aged subjects were able to transfer the provided optimal game strategy to game play despite a number of experimentally manipulated distractions. These findings suggest that players of educational games can benefit from a mix of traditional education (strategy tutorial) and game play.

Day, Arthur, and Gettman (2001) later found that the type of knowledge structures players used while playing games mediated the relationship between general cognitive ability and game performance. Specifically, subjects using the predetermined “expert” knowledge structure for the game performed significantly better than those who did not. Blumberg and Sokol (2004) found that players approach games differently in terms of goals and strategies. They classified these strategies as internal (e.g., reading instructions) and external (e.g., asking a friend for help) and found that frequent and older players were more likely to use internal strategies than their younger and less experienced counterparts. Hence, more experienced players tended to be more self-reliant in their gaming strategy.

**Cognitive Skills**

A large amount of research has examined the cognitive skills required for and resulting from game play (Sherry & Dibble, 2009; Subrahmanyam, Greenfield, Kraut, & Gross, 2001). As
early as 1984, Greenfield asserted that games could play an important role in cognitive development. Subsequently, McClurg and Chaille (1987) showed increased mental rotation ability after 6 weeks (12 sessions) of game play in samples of fifth-, seventh-, and ninth-grade students. Subrahmanyam and Greenfield (1994) replicated this finding in a sample of fifth graders who showed a significant increase in spatial ability from pretest scores after three sessions of playing a game that required spatial skills. In the same journal issue, Okagaki and Frensch (1994) reported improved mental rotation ability after 6 hr of game play in a college sample. Similarly, other researchers have shown improvement in spatial ability after game play (De Lisi & Cammarano, 1996; De Lisi & Wolford, 2002; Feng, Spence, & Pratt, 2007; Okagaki & Frensch, 1994). Additionally, several researchers have shown that individuals who are high in spatial rotational ability are more likely to choose games that require mental rotation skill (Lucas & Sherry, 2004; Sherry & Dibble, 2009) and perform better at them (Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Greenfield, Brannon, & Lohr, 1994; Moffat, Hampson, & Hatzipanayis, 1998; Quaisser-Pohl, Geiser, & Lehmann, 2006; Sherry, Rosaen, Bowman, & Huh, 2006).

Researchers have also explored other areas of cognitive skills that relate to game play such as visual attention (Green & Bavelier, 2003, 2006a); iconic versus verbal representation of processes (Greenfield, Camai, et al., 1994); attention, memory, and executive control (Boot et al., 2008); object location ability, verbal fluency, and targeting (Sherry, Rosaen, et al., 2006); and short-term memory skills (Green & Bavelier, 2006b).

Can video game play improve a constellation of cognitive skills, rather than simply one at a time? Bowman and Boyan (2008) found that success in a first-person shooter was a function of a subset of cognitive skills including targeting, mental rotation, and hand–eye coordination, suggesting that players use more than one cognitive skill during game play. Basak, Boot, Voss, and Kramer (2008) provide evidence that games can help develop more than one skill. After 7 weeks of playing a strategy game, a sample of older adults showed improvement in both executive control tasks and visuospatial skills over a control group. Like the producers at Children's Television Workshop, educational game designers may be able to increase impact by layering skill learning in addition to content learning.

CONCLUSION

The approach we provide here argues for two specific types of learning outcomes resulting from video game play: the creation of mental models of educational content and the development of a variety of skills. Designers can build these outcomes into intrinsic challenges within games, which are the engaging and rewarding component of game play. If designers build game models that mirror educational content and provide a variety of opportunities for skill development, gamers can learn content and develop thinking skills while playing highly engaging games. This approach leverages current pedagogical best practices including probing, scaffolding, prior knowledge application, and practice, as well as capitalizing on the mechanism makes games engaging.

At this point, many questions remain. Will mental models developed during game play transfer to the real world? What role will teachers need to play in transfer? Do manifest challenges matter? And, of course, how do these answers vary by age? Research is needed to understand the value of thinking skills learned during game play. For example, will improvement of mental rotation ability make it easier to learn dissimilar content such as geometry? How will the development of strategic thinking skills effect learning of science?

In the late 1960s, the Children's Television Workshop discovered production techniques to teach effectively children via television; these basic techniques continue to inform production of educational television today. We need a similar approach toward video games. Unfortunately, today's funding climate favors game demonstration projects that do not allow experimental manipulation of game elements to isolate basic game learning design principles. Research needs to focus on more fundamental questions of learning and transfer resulting from video games.

REFERENCES


