

Design Principles of Next-Generation Digital Gaming for Education

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Introduction

Over the past few years, academics, industry leaders, educators, and the lay public have begun noticing the staying power and creative drive of the digital gaming industry. While dot.coms crashed, the digital gaming industry soared, posting large profit increases.¹ In March of 1999, The PlayStation 2 graced the covers of *Time* and *Newsweek*. *The Sims* shattered PC gaming records, selling millions of units (PC Data, 2002). The digital games industry is both paving the way for online media distribution and bringing the promise of "virtual reality" to the masses, with millions of subscribers participating in immersive game worlds, such as *Everquest* and *Ultima Online*. *The Sims Online* (released in December 2002) and the impending release of other titles are expected to entice millions more to enjoy online gaming.

¹For a recap of recent performance of the games industry, see the International Digital Software Association Website: <http://www.idsa.com>

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In 1998, MIT held the first academic conference examining digital gaming as a creative medium and maturing industry.² In 2001, *Game Studies* became the first academic journal focusing exclusively on computer and video games, and 2002 brought the first academic organization dedicated exclusively to gaming—the Digital Gaming Research Association (DiGRA). The year 2002 also saw the opening of the first major international art exhibit dedicated to digital gaming. *Game On*, which launched at the Barbican Centre in London in the summer of 2002, traveled across Europe throughout the Spring of 2003.

With this new industry attracting significant audiences, gaining cultural recognition, and achieving such market success, perhaps it is no surprise that educators have also taken notice of contemporary digital gaming. Long ignored in most educational research circles and schools of education, educational computer games (often dubbed "edutainment") have mostly failed in the market place and have been criticized by educators and game designers for their lack of a sound pedagogical underpinning as well as their derivative drill and practice formats (Gredler, 1996; Rieber, 1996). In contrast, others, such as Prensky (2000), have argued that games are ideally addressed to an emerging generation of unmotivated or hyper-wired learners. At the *Game On* Conference in the fall of 2002, several educators suggested that integrating commercial entertainment games into the curriculum might address growing student apathy and boost sagging attendance rates (Egenfeldt-Nielsen, 2003).

The MIT Comparative Media Studies/Microsoft Research Games-to-Teach Project was launched as a response to this opportunity to explore the untapped potential of games for supporting learning. We think that games are a vastly under-explored medium for teaching and learning; indeed, for aggressive research inquiry well.

This article describes our initial research and development efforts and shares our hypotheses about the design of next-generation educational video and computer games, but these are far from the final answers on the educational potential of gaming. In fact, our work is nascent research. We hope that the assertions set forth in this article will be debated, expanded upon, and even refuted, so that our collective understanding of educational game design matures and deepens.

Why Gaming?

Critics may note that there is a long history of research on simulations and gaming as instructional

²See <http://web.mit.edu/cms/games/>

strategies, much of which can be found in publications such as *Simulation and Gaming*. In the 1960s and 1970s, there were dozens of studies on the impact of games as instructional strategies and, more recently, instructional technology (Gredler, 1996). These reviews generally conclude that games can motivate learners, but frequently find little evidence to suggest that games are effective or efficient in supporting learning.

Recent developments in gaming have led to exciting opportunities for combining lessons from emerging pedagogical/gaming models, continually evolving genre conventions, and development tools. Game genres provide a wide range of gaming experiences, such as navigating through interactive narratives (*Ico*); collaborating in complex problem solving (*Mind Rover*); raising digital life forms (*Creatures*); participating in persistent virtual communities (*The Sims Online*); exploring detailed simulated worlds (*Thief*); and playing with feature-rich authoring tools (*Civilization III*).

At the same time, pedagogical approaches such as case-based learning, goal-based scenarios, anchored instruction, and problem-based learning cast students in roles where they solve complex problems while frequently role-playing as doctors, scientists, presidents, or advisors. In these educational game scenarios, context is more than just a motivational wrapper; it becomes a critical component of the learning environment. In good educational games, narrative events situate the activity, defining goals, constraining actions, provoking thought, and sparking emotional responses as students struggle to resolve complex, authentic problems. When a student watches a patient die and must console her heart-broken mother and explain what went wrong, in a hospital simulation game, the fantasy of playing a doctor in an emergency room is a critical component of the learning process, not simply something to make the game more appealing. From a situated learning perspective, these narrative constraints and possibilities shape action, and become a part of students' understanding of a domain in fundamental ways.

Roger Schank (1994) provides concrete examples of how narrative events shape student understanding and how failure states can be linked to students' misconceptions of a domain. Schank describes how digital environments can induce failure states which are tied to students' misconceptions in a domain. For example, a role-playing game designed to help emergency workers respond to weapons of mass destruction might have a scenario in which a firefighter is dealing with a biological attack in a shopping mall. The scenario might include a crying baby infected with a pathogen; and if the emergency response worker rushes to pick up the baby without first protecting herself, she might become infected (see also CTGV, 1993; Keegan, 1995).

As Bransford and colleagues (1999) describe in *How People Learn*, knowledge is contextual, fundamentally rooted in the particulars of experience. The affordances and constraints of a situation affect how knowledge is constructed and subsequently used. Narrative context shapes behaviors, making certain courses more available and constraining others. Moreover, narrative context helps students to understand how core knowledge can be deployed, helping them to see real-world applications and develop an experiential understanding of what might otherwise remain abstract principles. Unfortunately, narrative and play have traditionally been given short shrift in most educational interventions. While goal-based scenarios and problem-based learning environments are based on narrative structures (causal chains of events), seldom do our interventions tell compelling stories; stories that a student, or anyone else for that matter, would find difficult to put down. What is missing is a treatment of narrative *content* specifically attuned to educational content, and intriguing in its own right.

Digital games offer more than just an interesting set of under-explored instructional strategies; they pose an implicit challenge to designers of educational media. Entertainment gaming experiences color players' interactions with other digital media, setting expectations for user experience and interactivity. Many educational microworlds are graphically primitive, lacking in aesthetic interest, and often years behind what is available in the commercial market. Our experimental microworlds may capitalize on some of the game-like elements of topics, such as physics or ecology, but rarely do they adopt the conventions common in even the simplest of shareware games, such as well-balanced levels, using power-ups, and creating fantastic or engaging characters.

Asking students to engage with games which lack the basic features they have come to expect from the medium is much like asking students of a previous generation to watch educational movies which lack sound or editing. While educational games need not have the stunning graphics of a *Doom III*, they cannot afford to ignore the models of interaction and representational expectations established by contemporary games. Game designers have begun mastering the basic building blocks of their medium, establishing modes of interaction and conventions for designing digital spaces that educational designers can use in the development of educational applications. We believe that by tapping into these developments, educators can create a new generation of educational media that captures students' imaginations that films like the *Bell Labs Science Series* or *Donald in Mathemagicland*, or television series such as *Mr. Wizard* or *Nova* did for earlier generations.

In outlining a framework for understanding the potential of next-generation educational games, this

article is a first step in opening up what Lloyd Rieber (1996) calls "exogenous play"—that play which is not removed from a learning experience, but inherent to it. We are interested in exploring the question of how to design educational games that are play spaces for exploring concepts, roles, and ideas, using the innately fascinating properties of science, engineering, or history as a context for play. As such, our goal is to envision games that work as both entertainment and learning experiences, to embody and communicate those processes and properties that drew professionals and scholars to those fields in the first place.

Design Principles

Over the past two years, our research team has designed 15 conceptual frameworks for games—experiments in design—that attempt to leverage the capabilities of next-generation educational media to support learning. These frameworks³ were designed to explore a broad range of different curricular content (from electromagnetism to colonial American history), a diverse set of game genres (from racing games to massively multiplayer environments), and a variety of different delivery technologies (from Pocket PCs to network computers). As fleshed out thought experiments, these conceptual frameworks attempt to concretize the intersection between contemporary game design and educational principles. We acknowledge that until they are built and tested, these frameworks remain speculative. We currently have three games in development. This article looks across these 15 designs to identify some core heuristics or rules of thumb which have guided our work. We hope that they may inspire others to engage in similar research.

1. Design educational action games by turning simulations into simulation games. Perhaps the simplest way to approach the design of educational games is to take a standard simulation, such as a model of magnetic fields which might be deployed in a physics classroom, and imbue it with game-like elements. Simulations and games share much in common. Both model a set of inputs and outputs, though commercial games often model fantastical rather than realistic environments. Structurally, games differ from simulations in that games (usually) have an additional narrative backstory and context, one or more goals and challenges, and various "failure" and "win" states. Students watch simulations from the outside;

³These frameworks are published on the Games-to-Teach Project Website: <<http://cms.mit.edu/games/education/proto.html>>. We use the term framework to suggest that the games are more than just game designs, but ways of thinking about learning and gaming that attempt to connect contemporary pedagogical theory with state-of-the-art game design.

they immerse themselves within games, and their more immediate participation expands the opportunities for mastering the content.

So, start with a simulation and then start adding challenges or goals which the player might carry out in that environment. Use those goals to motivate players to explore and map the properties of the simulated world. They will be motivated to learn the core principles and processes shaping the simulation in order to achieve their goals, overcome the challenges, and win the game. To be compelling, constraints must be added which make it difficult to achieve assigned tasks, whether relatively arbitrary, such as limits on interaction time or on the number of possible iterations, or more organic to the simulated situation, such as limited energy supplies or factors which might retard a vehicle's velocity. As the students scan the game environment looking for resources which can be deployed to achieve their goals, they need to not only see their own roles or situations but also develop an intuitive, qualitative understanding of how the system itself operates (see also diSessa, 1993).

The game board is a visualization tool for players to see concepts at play and a playground for exploring the properties of a system. As game critics have long noted, beating a game involves learning the logic upon which it operates. When the game then draws on real-world principles, this antagonistic relationship between player and software fosters new forms of learning. Such simulation games are hardly new in education; several software packages, such as *Thinker Tools* or *Electric Field Hockey*, use such techniques to give typical simulations a more game-like experience. Such common tools, then, contain the potential of transforming simulations into compelling interactive worlds waiting to be explored.

2. Move from parameters to "power-ups." Educational software designers often ignore the most basic of conventions, such as power-ups, which shape commercial games. For the benefit of the uninitiated, the power-up is a device used in platform games to adjust some trait of the character or their worlds, such as shifts in player speed, height, or friction. Players use power-ups to enhance their basic attributes; veteran players become adept at anticipating how particular power-ups affect possible actions. Educational designers can use power-ups and the subsequent choices they enable to get students to anticipate the consequences of different changes in variables. Power-ups can thus be a simple and effective trick to tie educational goals to the intrinsic motivational structures of games.

For example, power-ups are used as a way of addressing students' misconceptions about Newtonian mechanics in our game *Cuckoo Time*. In *Cuckoo Time*, the player is a gnome who lives inside a cuckoo clock, and the object of the game is to catch a cuckoo bird in

order to set it onto the perch so that it may chirp on the hour. The clock is a mess of gears, pulleys, levers, springs, pendulums, and other mechanical devices that the player must use to gain mechanical advantage and propel herself through the clock. Along the way, the player can use power-ups that modify her speed, mass, rate of acceleration, or friction. In doing so, the player must confront several problems which have proven difficult in traditional classroom exercises, such as, "What is the relationship between mass and the period of a pendulum?" The power-ups isolate these questions for the player and provide a visceral motivation for solving them. Although *Cuckoo Time* is not in full production, we imagine the game's levels and challenges being used for in-class demonstrations or lecture illustrations, homework problems, or even as exam questions. For instance, a physics teacher might observe students playing and discussing their games, listening to the strategies that players use, and examining what they might reveal about the players' thinking.

3. Design game contexts by identifying contested spaces. In "The Art of Contested Spaces," Jenkins and Squire (2002) argue that games are a spatially-based medium where the action is driven by contested spaces. In puzzle games, players manipulate space to match patterns. In action games, they frequently control or dominate space (clearing rooms of enemies). In strategy games, they conquer space, and in role-playing games, they explore unknown spaces. One way to think about potential game themes is to identify contested spaces, seeds for natural struggle or conflict.

Our game concept titled *Replicate*, for example, is another game built around the principles of simulated microworlds, although it is designed to support learning in virology and immunology. In *Replicate*, the player is a virus trying to replicate within a host organism (the human body) and, indirectly, throughout a population. The object of the game is to outwit the full force of the human immune response and maintain a level of viremia that allows the virus to be transmitted, yet not kill the host, upon whom the virus depends for survival. As the player navigates through the human circulatory system, he must find viable target cells, enter them, and shed his protein coat. Once inside the cell, the virus has a limited amount of time to reproduce before the cell is destroyed by phagocytosis. The player must quickly make copies of himself inside the nucleus. Skilled players learn how to read the body's immune system as they dodge antibodies and phagocytes. *Replicate* helps students to visualize the complex responses of the human body to infection, by leveraging the natural war between pathogens and the human immune system, that is, the manipulation of contested space in life and for survival.

4. Identify Opportunities for Transgressive Play. Katie Salen and Eric Zimmerman (in press) describe

how one of the satisfactions of game play is its potential for transgressive play, that play tied to the experience of temporarily letting go of social rules and entering a transitional space where social boundaries can be pushed and new roles explored. Noted game designer Warren Spector also talks about the importance of these playful experiences, building on anthropologist Frederick Turner's notion of "liminal spaces," spaces where social mores and cultural rules can be temporarily abandoned, re-examined, or even playfully transgressed (Au, 2001). We see games' ability to place learners in liminal spaces where they can engage in transgressive play as an engaging feature of games and an under-explored area for learning.

In *Replicate*, we try to build on this notion of transgressive play. In the context of *Replicate*, racking up a large body count is perfectly acceptable, even desirable. How players respond to this game dynamic is still speculative, although our initial design reviews with students have been positive. With *Biohazard: Hot Zone*, which is currently being developed with Carnegie Mellon University,⁴ we are trying to tie the potential for transgressive play to learning more directly. In *Biohazard*, players are emergency response workers learning procedures for dealing with attacks from weapons of mass destruction. Players can use the game to explore what would happen if they did not respond to an attack at all, or what would happen if they accidentally contracted a biological agent and infected other populations. Our focus group tests indicate that emergency responders valued opportunities for exploring different emergency response strategies within the safety net of a simulation. Future field tests will determine how these affordances of the simulation affect learning.

5. Using information to solve complex problems in simulated environments. Educators have long documented the difficulty students have in moving between the abstract formulas or principles presented in classroom exercises and using those same ideas in more complex social situations (e.g., Schoenfeld, 1991; Whitehead, 1929). One way to conceptualize educational games is to start by identifying real-world uses or applications of the knowledge which is to be taught, searching for situations which are narratively compelling and emotionally engaging. When would engineering be exciting? Perhaps if you were trapped in an alien spacecraft thousands of miles above the Earth with only a handful of parts that need to be put back together to get the ship home safely. When is cultural studies exciting? Perhaps when the student is a spy who must master the patterns of behavior of a people and pass as a native within a digitally simulated world.

⁴For the official *Biohazard: Hot Zone* site, see <http://www.etc.cmu.edu/projects/biohazard/spring03/>

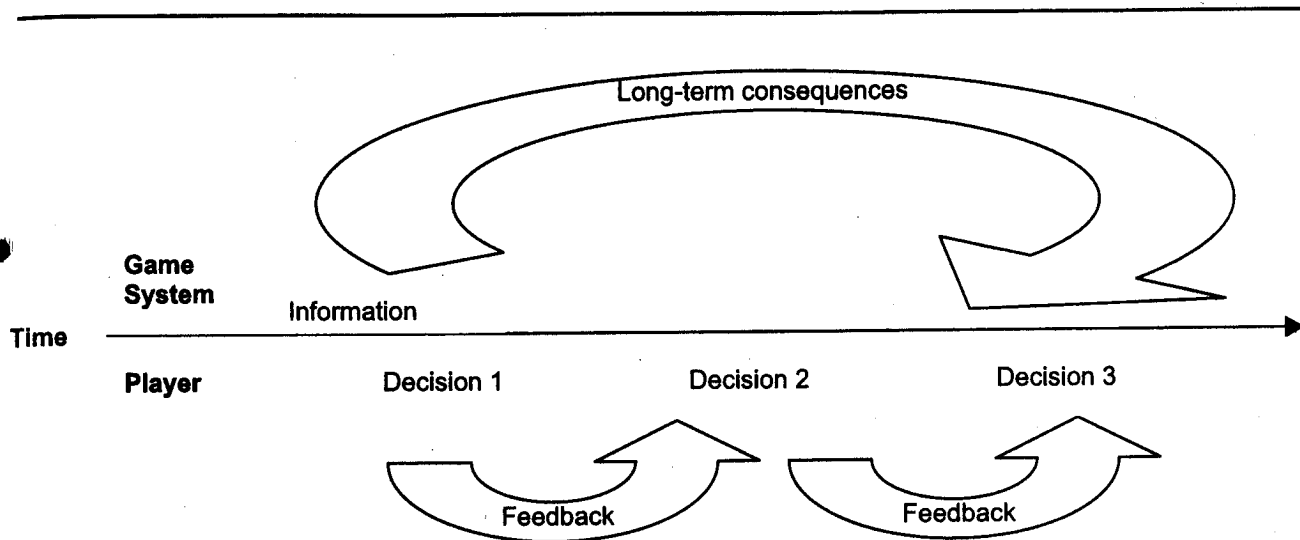


Figure 1. Cycles of choices and consequences, adapted from Zimmerman & Salen (in press).

Adventure and role-playing games provide models of puzzle-driven narratives that force players to *think with* acquired knowledge and skills.

Educational technologists familiar with the work of Roger Schank might recognize these strategies as a way that Schank and colleagues have designed goal-based scenarios (1994). Indeed, we see strong overlap between adventure role-playing game design and the design of goal-based scenarios, case-based learning environments, anchored instruction, and problem-based learning environments. As in each of these environments, role-playing games can engage learners in solving complex, authentic problems. They can give learners digital tools and resources for collecting and analyzing data. The difference is that thousands of people bought *Deus Ex*, but far fewer line up to buy "goal-based scenarios." We believe that role-playing games, specifically simulated role-playing games designed in the vein of *Deus Ex*, provide exciting opportunities for immersing players in engaging educational game environments, primarily through the shift from reading about educational content to *thinking with* that content to achieve compelling goals.

6. Provide choices and consequences in simulated worlds. We find the emerging genre of "simulated world" games (e.g., Spector, 2001) particularly exciting as a framework for thinking about educational role-playing games. In simulated world games, players are presented problems (not puzzles) and then are given tools, resources, and rule systems they can manipulate in order to solve those problems. In traditional adventure games, players are given a puzzle, say unlocking a door to which there is one and only one

(frequently arbitrary) solution. A classic example is the moment in *Grim Fandango*, a LucasArts game, when the player must cause an explosion with a fire extinguisher to open a locked door. In a simulated world, problems are open-ended and can be resolved in many different ways, depending on the player's ability to experiment and innovate with the materials in their environment.

Zimmerman and Salen (in press) argue that games can be thought of as overlapping, interacting causal chains of action where players are presented with information, make decisions, and then consider the consequences of those decisions (see Figure 1). Designing "interesting" decisions is a complex art. Simulated games are emergent systems, where the properties of game play emerge from simple sets of rules.

One relatively easy way that game designers can give players choices is to constrain the resources and tools that can be accessed in the game. Limiting the player's ability to access information or manipulate the world forces the player to evaluate (and design systems for evaluating) the relative value of information and to devise appropriate goals and strategies. In other words, limiting choice constrains action, which encourages players to invest in their goals and plans. As players experiment with choices and consequences, they develop and test hypotheses, building models about what they anticipate will be the outcome of particular choices or representations of the game world itself, and developing criteria for evaluating options. This iterative process of mapping and mastering games represents a powerful system for learning basic principles of the

simulated environment and then employing those principles through problem solving.

7. Differentiate roles and distribute expertise in multiplayer games. Massively multiplayer online world games where players create avatars and explore virtual worlds may be one of the most exciting opportunities for applying game designs and technologies to educational software interventions. One of the core game design mechanisms for encouraging collaboration is the notion of differentiating between different players' roles, so that players must collaborate to succeed in a world (Dede, 2001). This design mechanic goes back at least as far as *Dungeon and Dragons*, where dungeon masters design quests that demand multiple players with multiple skill sets.

More recently, the designers of *The Beast*, the Web-based game that was released in conjunction with Warner Brothers' *A.I.*, used a similar mechanic of distributed expertise to engage players around the world in a scavenger-hunt style puzzle game. Clues were simultaneously revealed in different locations spread across the globe, so that players must collaborate in distributed teams and communicate in real time to solve puzzles.

Multiplayer educational games can use this same technique to foster collaboration among groups. In *Environmental Detectives*, our location-based Pocket PC game, players conduct investigations trying to uncover the causes of a ground-water contamination. Players have limited resources (money and time) and must collaborate to use these resources most effectively. Players must organize to gather library-based documents, create effective sampling plans, and devise a system for treating the contamination. Our initial field tests indicate that these design features are helpful in supporting collaboration, communication, and reflection in action, and our future studies will focus on how these design features also remediate understandings of environmental science (Klopfer, Squire, Holland, & Jenkins, 2003).

Conclusions

These seven design principles only scratch the surface of what educational software designers might learn from a careful examination of commercial games. Some other possible lessons might include the ways that most games gradually increase complexity through careful level and mission design, constantly pushing the player to improve; the ways that choices in the control, camera, and interface conventions of games shape the player's relationship to the simulated environment; the instant and useful feedback games offer learners through scores and levels; and the way that multiplayer games use differentiated roles and tasks to encourage collaboration.

The term "game" is enormously elastic, describing a broad range of different kinds of entertainment

experiences; most of them have potentials for pedagogical applications, though none of them work in every situation. Too often, educators have talked about games as a monolithic medium; understanding genre distinctions, and the different kinds of social experience (and learning) they enable, should be the first step towards the design of next-generation educational software. In this article, we have tried to honor these unique aspects of particular game titles and genres, while articulating some of the guiding principles behind the Games-to-Teach Project.

We believe that good game design involves more than mimicking the structural features of games or the kinds of experiences they enable (fantasy, control, challenge, curiosity, collaboration, or competition); educational software designers need to develop an understanding of the core logic shaping those conventions and the ways that shifts in game design result in dramatic differences in player experience across titles within the same genre tradition.

To be effective, educational game designers need to be well-versed in the fundamentals of contemporary game design, much as educational filmmakers need to follow and understand the conventions of film (shots, cuts, and so on). At the same time, there is a conservatism in the games industry, caused by a reliance on very narrow markets, escalating production costs, and market pressures in an industry where the majority of releases, despite enormous success for some items, are market failures. We believe that the educational markets are critical spaces for experimenting in the outer edges of the medium, similar to the role of documentaries in film or television. □

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