COMPUTER GAMES

The universe of computer gaming is rapidly expanding and richly varied. In less than two decades, the idea of games driven by computer chips and software has gone from a novelty to a multibillion dollar industry. Game platforms from small hand-held devices to mammoth simulators outfitted with hydraulics, wrap-around visuals, and high-fidelity sound are offered. Within this broad spectrum are found games played on personal computers—the focus of this article. Fortunately, many of the design considerations are the same across all platforms.

Because of space limitations, no attempt is made to be comprehensive. The basic technical issues for game development are discussed, including imaging, sound, interfaces, and game concepts. A case study of three best-selling PC games contrasts how developers addressed these issues. The social context is examined, including concerns and benefits of the impact of computer games. Games specifically designed to be educationally beneficial are described. The article ends with a brief look at the future of PC-based games. The reader should also be aware of the rapid evolution of game technology. It is quite possible that anything mentioned in this article will be superseded by new technology within a short time frame.

ESSENTIAL TECHNICAL CHALLENGES

The design, implementation, and marketing of a computer game can be described as creating an engaging and stimulating environment within the restrictions of technology available to the typical consumer. Most consumers want faster, more complex, and more exciting games. In response, the game industry constantly pushes the envelope in applications of current technology. Early computer games were essentially the same as the most modern offerings, including the concepts of action, adventure, shooting the bad guys, and puzzles. Only the available technology separates them. This section discusses these unifying concepts and their evolution to present capabilities.

Images

The most important part of most computer games is the visual experience. While sound and other interface characteristics enhance the overall effect, without a visually interesting presentation the game has little chance to succeed with users. Further, imaging is often the most technically challenging and computationally intensive aspect of the development process. The root of the problem is the sheer volume of information that must be processed. A typical consumer's display will have a resolution of at least 640×480 pixels and at least 8-bit color (256 colors). This represents 2.4 million bits of data. To generate acceptable visual effects, animation rates need to be at least 18 to 20 frames/s. To generate a completely new full-screen image twenty times per second requires processing almost 50 million bits for just the display alone. Add to this the internal data structures for representing 3-D models, textures, shading, lighting effects, and other graphical entities, and the computational ramifications become clear. Obviously, first-generation PCs with their monochrome displays, limited memory, and low processor speeds fell far short of the computational power for this class of image processing. Modern games address these issues through a combination of algorithmic optimization and hardware improvements. An important hardware solution has been the advances in accelerated graphics cards. These effectively off-load a great deal of the computations from the CPU to dedicated processors residing on the card. Modern PCs also incorporate better architectures with efficient buffering and caching of often-used data. These advances have combined to allow artists, musicians, and programmers to create compelling gaming environments.

Animation. Animation can exist as pregenerated sequences substantially like animated cartoons. Artists will use software to generate each frame of a sequence which is then played on cue during the game. Other games render each frame at run time. This is done when there is no prior knowledge of the user's point of view within the game environment. Some games will use *sprites*—images that take up a much smaller portion of the view area. Each of these sprites is manipulated independently. The advantage to this approach is that only the area of the screen affected by the sprite needs to be redrawn.

The software used by the artists greatly speeds up the animation process. Traditional animation was a painstaking process requiring thousands of individual drawings for even relatively short amounts of time. Primary images for each scene were usually developed first, then drawings in between. Now there is computer software that can generate the in-between frames. The artists also have at their disposal modeling software that will assist in generating complex three-dimensional worlds. By positioning a virtual camera within this world, they can take a "snapshot" of the world from any point of view. They can then automatically generate frames by defining a path through the world, moving the camera along that path, and taking a snapshot at regular intervals. Artists also use kinesthetic modelers. These are useful for constructing animations of jointed figures such as people and animals. Information about the figure is stored in the computer so that when an artist repositions a hand, the arm moves along with it. All of the components of the figure are interconnected in this way, allowing rapid manipulation of the drawings for each frame.

An additional advantage of computer animation is that developers can easily correct mistakes. In the traditional art form, each cell is individually crafted and then photographed. If there is an error in the cell, it can require complete redrawing. Images stored on the computer, however, can be edited more easily.

3-D Images. Three-dimensional images are common in contemporary games. Even games that do not use a 3-D virtual environment will use sprites that have been rendered to give the appearance of depth. Rendering of 3-D space in real-time games can be a computationally intensive task. Sophisticated data structures such as binary space partition trees and bounding regions are employed to reduce the amount of computations needed for each frame. Lighting and shadows complicate this even further. Often objects in the virtual world will have complex surface textures and reflective properties. Casting of shadows can greatly increase the amount of calculations. The modeling software used by the artists automatically considers each of these factors as it renders each frame. This can create astonishingly surreal animations with exquisite detail and richness.

Sound

The integration of high-fidelity sound with computer games has vastly increased the overall sensory experience. From their infancy, computer games have tried to incorporate sound and music. The technology has progressed from low-quality (and, some would say, annoying) beeps from a PC's internal speaker to the present generation of synthesized and digital sound played through external speakers. Influential to the development of game sound and music were FM (frequency modulation) synthesis (1) and the MIDI (Musical Instrument Digital Interface) standard (2). FM synthesis is giving way to wave table synthesis (3), and MIDI is being augmented and sometimes supplanted by pure digital audio, but the two were instrumental in paving the way to interactive multimedia titles.

FM and Wave Table Synthesis. FM synthesis was the first widely used tone-generation technology for PCs. This was in large part due to its relatively low cost. The weakness of this approach is lower quality sound. Each tone is generated from sinusoidal waveforms that are combined to provide the desired effect. By using such pure waveforms, the resulting sound often lacks the rich tonalities of real musical instruments. Thus wave table synthesis is currently the preferred method. This method stores sampled waveforms of real sounds. Combining these samples creates synthesized sounds with all the depth and complexity of the real thing. Additionally, the waveforms can be combined in ways that are impossible with real instruments.

MIDI and Digital Music. Contrary to a common belief, MIDI does not directly record or play back any types of sounds.

What MIDI provides is a common format for computers to decode and convert into music. The format includes information such as duration, pitch, and volume for each note in the track. The computer then decodes this information and generates each tone using the sound card. General MIDI is an international standard that divides the music environment into multiple channels, with each channel being assigned a specific instrument or sound. This allows the MIDI data to be converted to the correct sound at run time. It is the responsibility of the sound card manufacturer to ensure that if a specific channel in the standard is assigned a cello that a tuba is not played. This allows music to be played properly on any sound card. What it does not guarantee is that the sound of the instrument will be identical from one sound card to the next. This depends both on the quality of the sound card and the synthesis method used.

With the advent of CD-ROMs the use of studio-recorded music is common. This completely avoids any problems with differences in tone generation between sound cards. Samples of sound effects are also often digitized and stored instead of being generated. This has had the effect of greatly increasing the sound quality of modern games.

Synchronization. Sound in computer games is conveniently divided into two forms, (1) background and (2) event-based. The background sound usually includes music and generic sound effects. A player walking through a dank dungeon might be hearing a dark, gloomy musical composition and the distant moans and grunts of strange creatures. This type of sound helps to set the overall mood and feel of the game. These soundtracks are usually stored on the CD-ROM or hard drive of the user and continually fed into program. The second class of sound is what creates the interactive aspects of the game. Opening a door may cause an audio track of a creaking hinge to be played. Shooting a weapon or killing a monster will generate a particular sound event to enhance the experience, and the programmers must analyze user input to determine the proper audio sequence to match the events. These sounds can also be stored on the CD-ROM or hard drive, or even physical memory if faster access is needed. This illustrates two separate forms of synchronization inherent in sound tracks. One is a generalized form that builds the mood. This must be synchronized with the particular scene or portion of the game. Playing the same background music throughout a game quickly becomes boring or, even worse, annoying. So, programmers, musicians, and designers often develop a predetermined sequence of varied tracks and code this directly into the game, synchronizing music and sound changes with the overall flow of the game. In contrast, the sounds that result from user interaction are nondeterministic. The programmers must write code that traps specific user actions, retrieves the appropriate sounds, and plays it in real time. Here the synchronization is with low-level events such as mouse clicks or key presses, and with internal program states such as notification from a collision-detection algorithm.

Additionally, these two sound forms must interact with each other seamlessly. When a user-initiated sound event occurs, the background sounds should not be interrupted or the flow of the game will be compromised. The background sounds should also never overwhelm the event sounds. Contemporary games address the first problem during design and implementation, taking into consideration the hardware capabilities of the typical consumer. The second issue is usually solved by allowing the user access to options that adjust the sound level.

Interfaces

Another important element of a computer game is the design of the interface. While this is clearly an issue for all software, the interface of a computer game is a crucial part of the gaming experience. A poorly designed and awkward interface will interfere with the "playability" of the game, reducing the entertainment value. Conversely, a well-executed interface will seamlessly merge with the game, effectively disappearing from the immediate consciousness of the user. Interface hardware is commonly a combination of mouse, keyboard, and joystick, with more sophisticated controllers being used for simulations.

Mouse and Keyboard. The mouse and keyboard continue to be the most common input devices for computer games. Joysticks are often used for flight simulators, first-person shooters, and other games, but the complexity of games still often requires the keyboard to allow for access to all of the game's options. For instance, a shooting game will usually have multiple weapons, or a flight simulator may employ many different parameters relevant to staying in the air. The keyboard will have many of these user choices bound to specific keys for quick access during the game, with the joystick functioning as the primary controller. The mouse is used as a controller for direction in some games and as a pointer in others.

As a direction controller, moving the mouse forward will cause the character's position in the game environment to move in one direction; moving it to the right, left, or backward will cause movement in other directions. The mouse can also be used for rotations in the game space. Combinations of keystrokes and left, center, or right mouse clicks can allow extra degrees of freedom beyond the mouse's basic two-axis movement, as well as additional actions such as firing weapons.

As a pointer, the mouse functions similarly to a typical windowing environment. The user will move the mouse cursor over the playing area, clicking on items of interest to initiate various game interactions.

Care must be used in designing a game around large number of keyboard "hot" keys, as well as mouse and keystroke combinations. The temptation is to provide the user with a large number of options for manipulating game parameters in real time. However, this can make a game difficult and frustrating to learn and discourage beginning players. Flight simulators are a good example of the high learning curve in a complicated interface. As the computer representations of flight have increased in accuracy, the number of flight parameters available to the user has also increased. So complex are some of these games that a beginner cannot even take off or land. Developers have worked around this by providing beginner scenarios where many of the options are turned off or put under computer control.

Advanced Controllers. As games are becoming graphically more sophisticated, the level of realism in controllers is increasing as well. Consumer outlets now have flight systems with a yoke and pedals. Racing car simulations can have a steering wheel and pedals as an interface. Also, controllers are available that provide tactile feedback. These devices will 'push back' against the user with force relevant to the current state of the game, mimicking a steering wheel pushing against a real driver during a hard turn. As these devices are perfected, the game experience will become even more realistic, with a higher degree of immersion in the environment.

Virtual Reality (VR) Systems. The current technology also supports relatively sophisticated virtual reality (VR) systems at consumer prices. These systems will use some type of stereo vision technique for a true 3-D effect. Sound and vision are often integrated into a single helmet-like unit, completely immersing the user in the game environment. The effect is strong enough to cause motion sickness in susceptible individuals. No doubt, as these systems become more affordable and more technically sophisticated, they will play an increasing role in the design of computer games. The merging of the advanced input devices with VR imaging systems will push the envelope of computer games into increasingly realistic and powerful sensory experiences.

Game Concepts

Arguably, the most important aspect of a game is its concept. Great graphics and sound can still make for a boring game. Simply rehashing an existing game into a slightly different package risks what might be called 'sit-com syndrome.' Any breakthrough situation comedy invariably spawns a batch of similar fare when the next season rolls around. The copycats rarely do as well in the ratings as the original, leaving television with a plethora of mediocre offerings. Computer games suffer from the same malady. Imitations trying to capitalize on a concept will quickly follow a phenomenally successful game. It behooves a designer to spend a great deal of effort in developing some original themes for a game.

Computer games can be loosely grouped into several categories; puzzle/board, arcade, action/adventure, shooters, simulators, strategy, multiuser dungeons/role-playing, and educational (the last of which will be discussed in another section). This is by no means a formal or comprehensive division of the game genre, and many games will show considerable overlap between these categories. No doubt, some designers might prefer other groupings, but these suffice for this discussion.

Puzzle/Board. Puzzle and board games are often computer versions of standard games like chess, checkers, guessing games, and card games. Incorporating the latest multimedia technology into these types of games is typically more difficult to manage cohesively. Simply laying in a music soundtrack and sound effects does little to enhance the "playability" of a game such as chess. Designers must consider the nature of the game, assessing how music, animation, and sound effects might enhance or detract. Simply packing in all the available innovative multimedia will not guarantee success. Some computerized games in this family will create environments that cannot be duplicated in a physical game. A board or playing area that changes throughout the game is possible, as are objects that violate laws of physics. This ability to create alternate realities provides a rich vein of imaginative and creative concepts and can be applied to all game types.

Arcade. Arcade games are such offerings as pinball simulations and PC versions of video arcade classics. These generally require a great deal of hand–eye coordination and supply an almost continuous stream of targets, falling objects, traps, and surprises. The goal is often to proceed through increasingly difficult levels of the game, always attempting to beat the highest score. Here multimedia is a natural fit, with fast-paced music and a barrage of sounds building an almost frenzied pitch into the game. The successful arcade game has a hypnotic quality, allowing the user to tune out external stimulation and become absorbed in the action. It is actually a compliment when a reviewer characterizes one of these games as highly addictive.

Action/Adventure. Action or adventure games are more difficult to characterize. Here the ideas of an engaging plot and well-developed story become more important. These games often incorporate elements from the other game genre. Graphics, music, sounds, and the story must be carefully crafted into a cohesive whole, with each piece making sense in the context of the entire game. The user is usually led through the game by a combination of narrative, clues, puzzles, and action sequences to the climactic end, where the hero rescues the universe from some heinous evil. An interesting twist is for these games to provide multiple endings, where the outcome is dependent on the actions of the user. Without such multiple endings, games are often played only once to the conclusion and not revisited.

Shooters. Shooters are exactly what one would expect. Usually the player is running around inside a castle, dungeon, or labyrinth, spreading carnage and mayhem among the denizens of the keep. The most popular of these games use some type of 3-D graphics engine and provide a high level of freedom of movement within their virtual worlds. There are two primary viewpoints for the player, first person and third person. A first-person view is seen through the eyes of the character, whereas a third-person view is like a camera looking at the character. Usually a third-person view is obliquely above the character. A first-person view provides a greater sense of motion and immersion in the game, while a third-person view can allow a wider-angled image.

Simulators. An important segment of computer games seeks accurately to simulate real-world experiences. The best example of these is flight simulators. The rapidly increasing sophistication of these simulations includes progressively better models of the physics of flight, high-quality graphic rendering, realistic sets of controls, and a steep learning curve. Flight simulations are no longer simple joystick-operated toys. There are also simulations for tank battles, warships, and submarines, among others. An increasingly popular form of simulators involves sports.

Strategy. Clearly, many games will have components of strategy. Some, however, are designed with strategic thinking as the central core of the theme. These games will typically force the user to consider the game's outcome based on the present state of the game. Long-range planning and being able to see the whole picture are essential for the user to successfully navigate these types of games.

Multi-User Dungeons and Role-Playing Software. The key element of this software category is the development of the users 'personal character.' Here the player can assume the identity of a mythical creature, an evil ogre, or many other creatures. As the user gains experience and develops and deepens the personality of the character, the role-playing aspect is increasingly important. The character is often assigned attributes such as strength and endurance, which will increase throughout the game.

Multi-user dungeons (MUDs) are often the environments in which these roles are played out. The dungeon will be explored by a group of characters, each controlled by a separate player. As battles are engaged and quests undertaken, each character has the chance to build up experience and attributes.

CASE STUDY OF THREE BEST SELLERS

For a computer game to be successful, all of the above issues must be addressed and implemented in a cohesive, engaging environment that leaves all of the technical aspects completely transparent to the consumer. Thousands of games have been released as both shareware and commercial products. What separates these top echelon games from the rest? It is difficult to offer a formula for success, but instructive to examine some of the top hits and see how each addresses the technical aspects of game programming.

MYST

Myst (copyright 1993, 1996, Cyan Inc. and Broderbund, Inc.) can be described as a first-person puzzle/adventure. The basic concept is to solve a sequence of puzzles and hence solve the mystery presented by the story line. What distinguishes Myst from other computer games is what it does not have: violence, sex, and frenetic action sequences. Much of what is commonly considered essential for a successful computer game is abandoned. Instead the authors developed a detailed story line and created an extraordinarily detailed graphical environment with rich and moody music. The animation in Myst is almost trivial (not lacking in detail or quality, but in scope). Movement through the game consists of a sequence of still shots that depict different views of the locations within the story. A scene may have levers or buttons that the user can activate with the mouse. Sometimes doors or objects may move. However, these sequences generally occupy a small portion of the viewing area and, as such, require much less computing power than a complete 3-D modeler. Full-screen animations are fully rendered ahead of time and the technical challenges of 3-D animation and real-time rendering are avoided. The designers focus on the detail of the images and integration with the story line, providing perceptual depth. Myst is something of a phenomenon, in that it spawned a number of ancillary products and three fantasy novels.

Descent II

Descent II (copyright 1996, Parallax Software) is classified as a first-person shooter. The player is the pilot of a spaceship. The enemies are robots hiding in extraterrestrial mines. The goal is to eradicate the robots. Descent II departed from the typical shooter of its time by the quality of its 3-D modeling. Complete freedom of movement in a 3-D virtual environment provides the head-spinning type of thrills expected by users. The movement through the environment is so fast and fluid, that it is possible for susceptible individuals to experience motion sickness. Unlike Myst, which draws the player into the plot through clever puzzles and clues, Descent II assaults the senses with a barrage of movement, explosions, and background music. What is sacrificed for such a dynamic environment is the high level of detail of Myst's images. The robots are clearly assembled from polygons, the walls tend to be flat, and the textures throughout are often grainy. While no doubt the makers of Descent II would like to have had photorealistic detail in their images, this was not feasible because of computational constraints. For complete 3-D freedom, every frame of a full-screen animation must be calculated and rendered. Since the particular view and location of the player cannot be known beforehand, images cannot be created and stored for later retrieval. Descent II also provides a level editor. This is actually instructive for those curious about how texture mapping, lighting, and many other graphical techniques are executed.

Diablo

Diablo (copyright 1996, Blizzard Entertainment) is a role-playing, third-person shooter. An evil entity possesses the son of a king and hides in the depths of a labyrinth. The player chooses a character type and attempts to slay the monster. As role-playing games go, this one is somewhat weak in its character's development and flexibility. There are only three classes of character and a limited number of attributes. This is not because of a lack of imagination on the part of the designers, but rather the limits of realistic playability. Here the designers have compromised between the complete 3-D virtual world of Descent II and the static images of Myst. The characters and monsters are 3-D rendered sprites that move through two dimensions. The rendering of each figure is done from eight different viewpoints, and the actual movements are predefined. By having prerendered sprites, the designers were able to provide a high level of detail and texture in both the characters and environment. Close observation reveals that the game area is divided into a grid. This division of the plane allows for significant optimizations of the algorithms used for such things as collision detection and object occlusion. One of the significant factors in this game's success was the utilization of the Internet. The developer provided free servers for multiuser games in contrast to the fees other developers required.

SOCIAL CONTEXT

Opponents call video games at best a waste of time, at worst, harbingers of real violence. They say instructional computer games are too abstract for children, too mindless, and too competitive. Proponents note that computer games can be motivational, responsive, therapeutic, and potentially social (4). While there is undoubtedly truth in both viewpoints, some claims are overstated. This section addresses both video and instructional computer games.

Who plays computer games? The main players are male adolescents. In the United States and the United Kingdom, about 90% play at some point, with about 65% to 77% playing daily for 30 min to 1 h and about 50% playing in arcades. About 57% to 67% of girls play at home, but only 20% in arcades. However, players vary widely and show little evidence of uniform personality (5,6). Furthermore, owning one's own video machine does not appear to greatly alter a child's activities (7). Children prefer games that can be categorized as fantasy violence and sports games, with only 2% preferring games that are educational (5).

Concerns

Given the high rate of play, at least by some populations, addictiveness has been raised as a concern. Although most people do not display such behavior, about 7% show signs similar to gambling addiction. They play much more than others, averaging approximately 30 h/week. While video games use up time and money for all who engage in them, this small but significant group may suffer from gaming dependency. (6).

Given children's preference for violent games, a second concern is that video game playing might increase aggression. The amount of aggressive behavior of four-to-six-year-olds increased following participation in a video game with aggressive content, although the absolute level of aggression did not vary from that exhibited following the viewing of an aggressive cartoon (8). Similarly, children's prosocial behavior decreased after playing the video game. Other research indicates that playing violent video games can arouse aggressive behavior in children from early childhood to college age (9–11). The level of violence in the game is also a concern: the more graphic and intense the violence, the more aggression is aroused.

Taking a cooperative or competitive stance may mediate these effects. For example, competitively oriented games reduce older children's generosity (12) and encourage additional aggressive game-playing (e.g., "overkills" increase). Taking a cooperative stance, in contrast, may reduce aggression (8).

So, playing violent video games, especially in a competitive stance, may increase aggressive behaviors. This is a complex question, however, and most studies have only examined short-term effects using a variety of measures (some of which may lack validity). Further, results are not all consistent. However, given that research from other media, especially television, indicates that depicted violence can increase aggressive behavior and attitudes (13), one may wish to be conservative on the effects of violence in video games (6). Children prefer video games over TV in part because they have greater control and are more active, so there may be cause for greater concern over the link between aggression and video violence. Television research may have one last implication: Violent content per se is not necessary for capturing and holding attention; fast-paced movement and special effects elicit attention, in both violent and nonviolent settings (13). There is a need to examine whether high-action but nonviolent video games might ameliorate effects on aggression.

A third concern is that video game use will prevent children from socially adjusting. However, surveys indicate that frequency of video game play is not related to children's popularity among classmates (14).

A final concern relates to gender. Some fear that children's attitudes toward gender roles may be influenced by video games, in which women are usually cast as persons who are acted upon, rather than as initiators of, action. Many take such gender biases as unsurprising, arguing that most video games are "games for boys written by older boys." This is reflected in gender differences. Boys show greater arousal and emotion than girls when introduced to video games. Males play for competition and to master the games, whereas females often are encouraged by their society to prefer more whimsical, less aggressive and, to some extent, less demanding games (6,15). Boys may "learn how to learn" video games (and be more willing to experiment without understanding the rules) and thus benefit more from practice, though differences diminish if girls do obtain extended experience (16).

In summary, video games reflect society. Sex bias, gender stereotyping, and violence are mainstays of most games. There can be negative effects, such as increased aggression after play. Video games' influence on children should continue to be charted and alternatives examined. Whatever the reason for gender differences, it should be ensured that girls are not disadvantaged in mathematics, science, and technology. Efforts might include developing games that possess more active, leading, female characters, social interaction without violence, dramatic narrative, richly textured video and audio, collaboration rather than competition, and simulation.

Benefits

The potential value of video games has also been examined. Video games may be as useful as other types of games, allowing children to control their environment and engage in developmentally appropriate play, from practice play to social play to games with rules (4). Some have claimed that video games increase social interaction and growth, attention span, motivation, hand–eye coordination, cognitive skills, and sense of mastery. Research is only beginning to test these claims, but does offer some information.

For one, video games have proved useful as tools of assessment and research in many fields, from psychology, education, to medicine. Palpable areas include the use of games as valid tests of psychomotor (6) and spatial skills (17) and research on the role of automaticity in performance (e.g., in controlling aircraft or power plants). Researchers have also used video games to study brain activity (e.g., type of forebrain activation while learning a video driving game); reaction time of hyperactive children; disorders from attention deficits to schizophrenia (where the games are useful for evaluation of attitudes and responses, psychological testing, motivation, and reward); behaviorism (e.g., games as contexts for arranging contingencies of reinforcement that are integrated into the experimental task; i.e., the video game); models of human learning of visual patterns, skills, language learning, and strategies (18); cognitive and metacognitive processes involved in problem-solving; benefits of collaborative learning (e.g., double training efficiency with pairs of learners compared with individual learners); cardiovascular reactivity of males and females to stress; and how to fight debilitating effects of aging (e.g., improving memory with specially designed computer games) (45).

Video games can also constitute effective interventions. Again, some seem straightforward, such as the development of spatial skills, particularly the dynamic representation of space. Video games are an effective and motivating approach to developing some such skills, especially for those initially weak in spatial ability (16). The popular game Tetris (Blue Planet Software, San Francisco), for example, has been shown to build spatial abilities (19). An educational modification of that game showed strong positive effects on spatial abilities and on the establishment of spatial-numeric connections; they also provided information about students' strategies for solving the unit's spatial and spatial-numeric problems (20).

Other areas in which video game interventions have been used successfully include movement rehabilitation; imparting information to young offenders, increasing impulse control; teaching about AIDS, drugs, and smoking; and developing problem-solving and creative abilities (1994). Games have been found to be useful in play therapy, though use can be difficult and slow, as well as other types of therapy. For example, psychiatric treatment for adolescents might include adventure-fantasy games that simulate typical life situations, and mystery games in which children learn by observing and modeling the behavior of the group leaders as well as participating in the development of successful problem-solving strategies. As a final example, one system addresses attention deficits by advancing the concept of biofeedback; the video game becomes more difficult as the player's brain waves indicate that attention is waning (21). Another series challenges users to test their knowledge on a topic such as health and medicine with quiz games. Then, simulations challenge users to apply health information in nonjudgmental, hypothetical situations. Games may not have to be designed with particular learning objectives in mind. Games that are selected by children may well provide opportunities for complex learning (4). Games specifically designed for learning are discussed next.

There are many other types of popular games that have not been studied. For example, research is needed on adventure games, such as the complex games played cooperatively by many people from distant locations (e.g., MUDs).

Conclusions

Video games embody specific social and symbolic constructs. Gender stereotyping and violence are ubiquitous. This can lead to negative effects, such as increased aggression. Video games' influence on children should continue to be charted and alternatives examined. Used differently, however, the potential value of video games is considerable. They are useful tools of assessment and research, and have positive effects, from the development of spatial skills to enhancements of creative abilities to amelioration of attention deficits.

INSTRUCTIONAL COMPUTER GAMES

Teachers recognize the appeal of games and often include games as components of their students' classroom experiences. Computer technology, especially with its interactivity and multimedia capabilities, creates new possibilities for instructional games. Will these new possibilities be more effective than other, admittedly less expensive, approaches? Why use instructional computer games? Two main reasons are for motivation and to focus attention on the educational goal (22,23).

Research has begun to identify attributes of computer games that motivate and focus people. Four are challenge, fantasy, curiosity, and control (15). Challenge depends on having a goal and receiving feedback about reaching it. Attainment of the goal must be uncertain for the game to be challenging. This may be accomplished through variable difficulty level, multiple-level goals (e.g., environments that include score-keeping and timed responses), hidden information, and randomness.

Fantasy refers to the evocation of mental images of social or physical environments not actually present. Ideally, fantasy should be intrinsic, that is, intimately related to the use of the skill. Intrinsic fantasies are often more motivating and students are more likely to be interested in the subject matter in the future. Also, connected, vivid images aid memory.

Curiosity involves the elements of novelty or surprise that are incorporated into a game. Curiosity can be both sensory and cognitive. Sensory curiosity involves attention-getting changes in graphics or sound. These can enhance the fantasy, function as a reward, or enhance conceptual understanding. Cognitive curiosity can be aroused by showing students that their knowledge structures are incomplete, inconsistent, or unparsimonious. Finally, control includes the choices or factors that players can regulate concerning various aspects of a game.

Computer games have additional instructional advantages (23). They can promote active learning. They are well suited to support the development of process skills, from problem-solving to decision-making to communication. They can also introduce new ideas, reinforce information and skills, aid transfer of learning, and individualize instruction. They can change educational roles, even allowing the teacher to be an ally instead of an evaluator (22). They can provide situations for learning that are authentic for students, possibly more authentic than the ostensibly "real-world" applications often used. However, these advantages are not guaranteed. Research suggests that the use of noncomputer games raises achievement *if* they are carefully selected to match curricular goals. If games are not pertinent to the content to be learned, or if they are not matched to student needs, they can lower achievement. Further, caution should be taken when transferring off-computer games onto the computer. Finally, the appropriate type of game must be chosen; this issue is addressed next.

Types of Instructional Games

General characteristics of computer games include, in addition to the previously described motivating elements, a specific goal, artificial rules, competition, and entertainment (22). However, types of instructional games vary widely.

The first type—the most common type used in schools—is routine practice in a game-like format. For example, many pieces of software transport drill in arithmetic facts to an outer-space setting. Such drill can be effective if the game actions do not displace instructional time (24,25). For example, second-graders playing a computer game for an hour a day for two weeks responded correctly to twice as many items on an addition facts speed test as did students in a control group (26). However, overemphasis on isolated skill learning is not consistent with recent educational recommendations (27).

The second type is the strategic game. For example, How the West Was One + Three × Four (Sunburst), depicts a race between a stagecoach and railroad engine (see Fig. 1). Spinners on each turn generate three numbers, which must be combined with the four arithmetic operations (each used only once) and parentheses, to generate a number. That number, which the player calculates, specifies how far the vehicle will move. If the player lands on a city, he or she automatically proceeds to the next city. If one lands on a shortcut, one takes the shortcut. If one lands exactly where the opponent is, she or he sends the opponent back two towns. The computer will give advice on the best move. This is practice, but it is *strategic* practice, both in the flexible combining of the numbers and operations, and in planning an optimal move.

In the third type of games, the concepts to be learned are intrinsic to the structure and content of the game. For example, in one program children learn about coordinates by selecting points on a grid so as to create a picture. As another example, "Darts" (Control Data Corporation), and the many imitators it has spawned, is an example of a game in which the mathematics is intrinsic to the content and structure of the activity. In it, students explore the placement of rational numbers on the number line. They shoot darts at balloons attached to the number line by estimating their positions on the line. These estimates can be in the form of fractions, decimals, mixed numbers, and expressions. When a dart hits the line, students receive significant mathematical feedback that goes beyond "right or wrong." They see how their guesses relate to other positions on the line. They can use this information to correct misconceptions (such as "$-1\frac{1}{2}$ will be between -1 and 0") and as a valuable referent for their next guess (e.g., "That $\frac{3}{8}$ was just a little too high. I bet $\frac{5}{16}$ will get it"). It opens the way for serendipitous learning, as when a student first guessed $\frac{3}{4}$ and then $\frac{6}{8}$ and discovered the darts hit the same point. Another student was startled to find that there was a number between $\frac{6}{7}$ and $\frac{7}{8}$! Finally, it encourages the construction of strategies, such as using the width of a pencil for a unit (which might be $\frac{1}{15}$ on the number line), or purposely shooting $\frac{1}{5}$, $\frac{2}{5}$, $\frac{3}{5}$, and $\frac{4}{5}$, regardless of the balloons' placements, just to get reference points.

Simulations, another type of game, are models of some part of the world. Computer simulations are mathematical models based on real-world information that attempt to respond in realistic ways. So, simulations have an additional ingredient compared with other games. They are designed around a dynamic working model. The game scenario is influenced by the player's actions so that it changes in much the way that the reality being simulated would change.

Some express concern that simulations could replace a valuable hands-on activity with an unnecessarily vicarious and abstract one. Good simulations, however, allow greater control of a situation (e.g., a pendulum swinging) than do real objects. In such a case, careful comparison of a simulation and a real-world event may benefit students (28). As another example, students often study Newton's laws of motion and can use formulas to solve problems, but maintain misconceptions. A simulation game has helped students integrate their knowledge and correctly analyze problems. The game embodied Newton's laws in a way that linked everyday beliefs about force and motion to formal physical knowledge, provided feedback as to how these beliefs fail, and focused attention on areas where their knowledge needed revising (29).

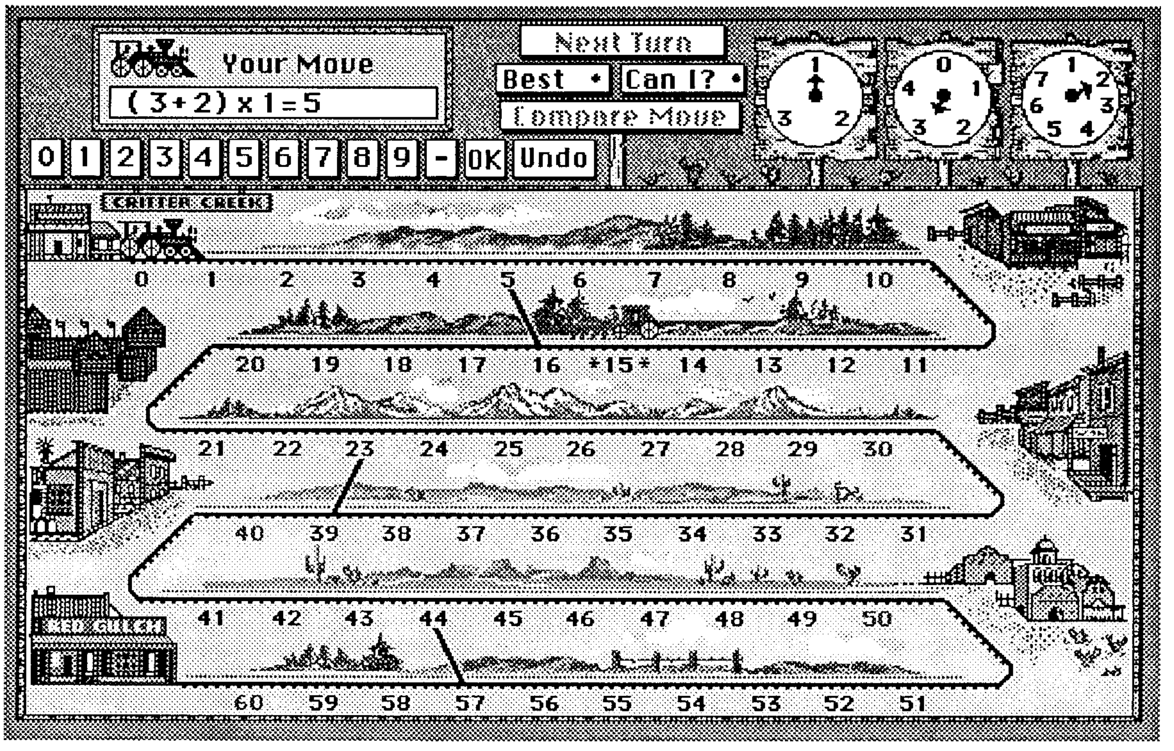
Many simulations are of social and political situations. For example, students might take the role of president, making policy decisions affecting poverty and inflation rates and receiving feedback in a graphic format on the effectiveness of these decisions. Simulations of events such as running a store or making ethical decisions when faced with a simulated classroom social problem may lead to excellent conjectures and discussions. One popular series of simulations is illustrated by SimCity 2000 (Maxis) (Fig. 2), in which the user plays the planners, designers, and mayor of one or more cities. One can choose to build small, rural towns, or huge cities. As one designs and builds cities, simulated citizens move in and build their homes and workplaces and raise families. The number of these citizens increases if the city is attractive to them and decreases if not. A main challenge is to balance raising taxes and maintaining a high quality of life. Simulations requiring teens to make decisions regarding drug use and respond to the consequences of such decisions have been shown to reinforce the attitude of teens who are not inclined toward drug use (30).

Used carefully and critically, simulations can help children explore and develop intuition about events and situations that are too dangerous, expensive, complex, or time consuming to experience directly. If the teachers facilitate transfer, they may promote decision-making, problem-posing, and problem-solving abilities. Simulations aid learning by simplifying the phenomenon. To promote transfer, they should add detail to imitate reality more closely as the student gains competence. Teachers must also encourage reflection. Many popular and interesting games, in which students simulate building cities (Fig. 2) or ecosystems, often do not realize their educational potential due to a lack of reflection and discussion.

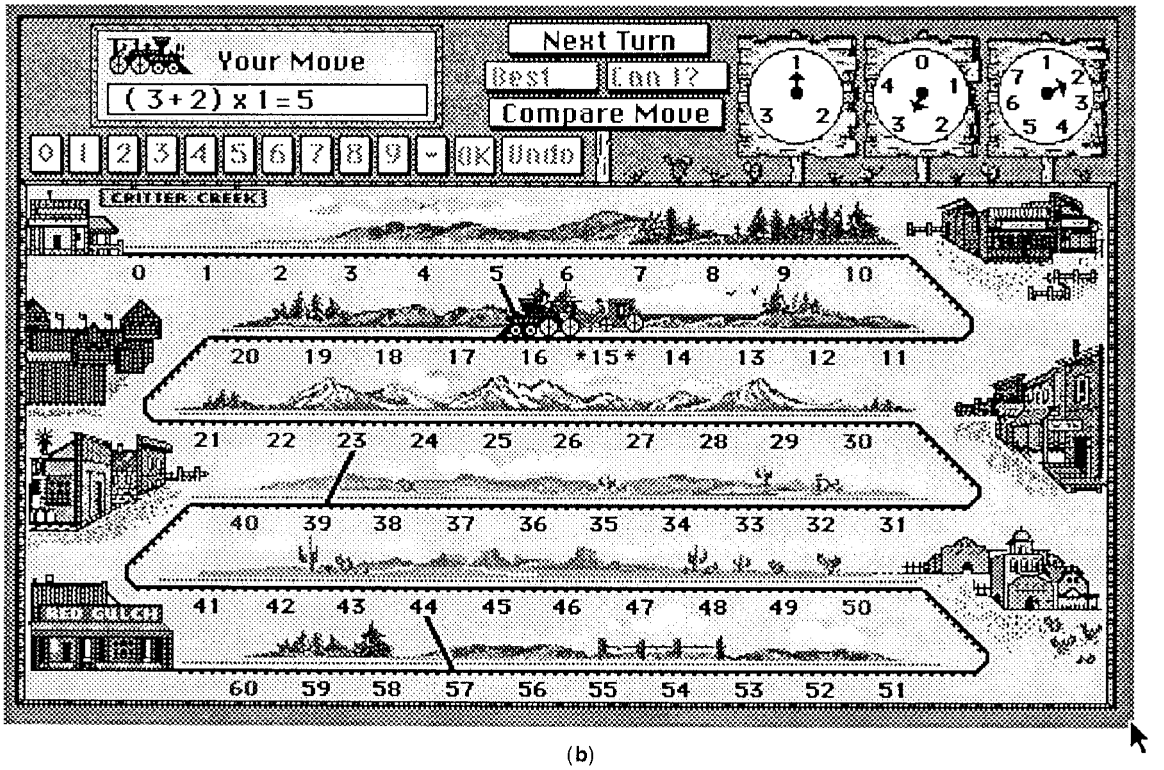
Some have attempted to build even more intelligent simulations to encourage such reflection and learning within the simulation (31). These environments can include large libraries of stories on video, told by experts in particular fields. The student can hear these stories and learn from them when they need help. The programs are designed around particular learning goals, creating scenarios where students are motivated to accomplish tasks that lead to successfully attaining the goals in question. For example, students may be placed in a new job position and have to interact with peers and clients. Such goal-based scenarios can be used for any subject matter, with any age student. Students learn how to actually do things rather than memorizing isolated factual material. Simulations and other instructional computer games can be effective when they help students learn by doing. They can direct their own learning, follow their interests, and achieve goals they set for themselves (31).

Social Interaction

Games involving cooperative interaction can improve children's social behavior (32). A computer simulation of a Smurf (Coleco Industries) playhouse attenuated the themes of territoriality and aggression that emerged with a real playhouse version of the Smurf environment (33). This may be due to features of the computer; in the computer environment, the Smurf characters could literally share the same space and

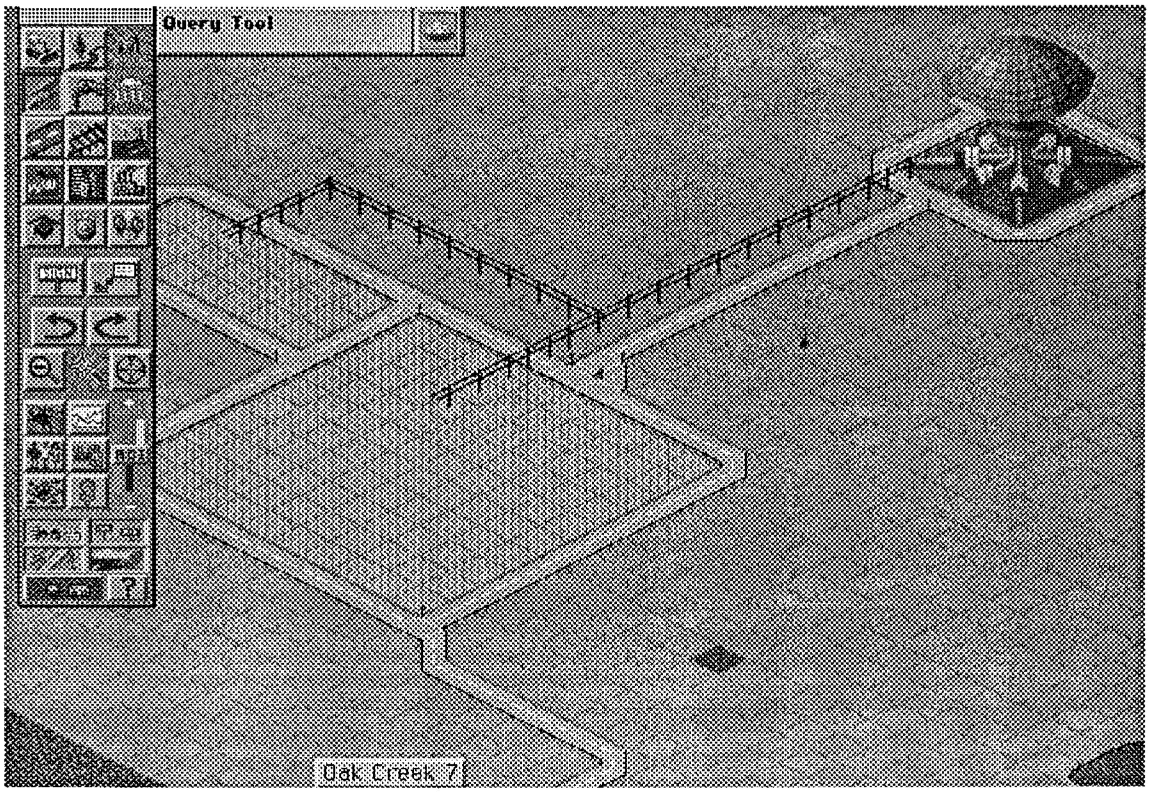


(a)

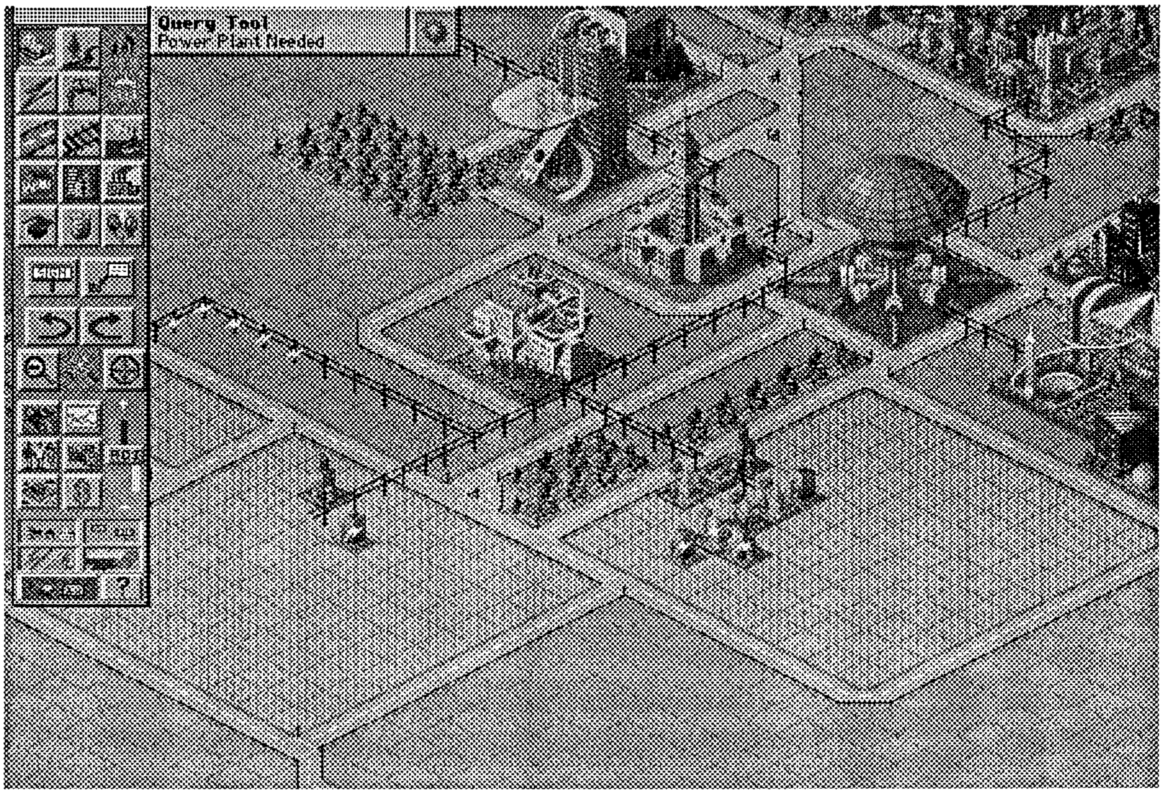


(b)

Figure 1. As the stagecoach in *How the West Was One + Three × Four,* this player has decided to construct a response (a) that is smaller than possible, but will land on a shortcut, enabling her to pass the train at "15" (b).



(a)



(b)

Figure 2. This player of *SimCity 2000* has begun (a) by designing a land area next to water, then has built several areas surrounded by roads. His next step (b) was to build a power plant. He is responsible for building other city structures, but the number of people and businesses that develop are automatically simulated by the computer.

could even jump "through" one another. The "forced" shared space of the computer program also caused children to talk to each other more.

In addition, computers may engender an advanced cognitive type of play among children. In one study, "games with rules" was the most frequently occurring type of play among preschoolers working at computers (34). Similarly, the dominant mode of cognitive activity is functional and constructive, and that functional play is higher on those days in which children are using the computer compared to days it is not in the classroom (35). Thus, already prevailing patterns of social participation and cognitive play were enhanced by the presence of computers. In a similar vein, children are more likely to get correct answers when they work cooperatively, rather than competitively, on educational computer games (36).

Teachers promote such interactions most successfully when they provide "just enough" guidance, but not too much. Intervening too much or at the wrong times can decrease peer tutoring and collaboration (37). On the other hand, without any teacher guidance, children tend to "jockey" for position at the computer and use the computer in the turn-taking, competitive manner (38).

Virtual Reality and Artificial Intelligence (AI)

Simulating reality can be more vivid in virtual reality environments. Students might, for example, wear headgear that tracks their head movements and provides 3-D images. A glove tracks the position of their hands. They could then see and even "touch" an imaginary world, possibly one in which physical laws have been changed. Environments may eventually have virtual peers, assistants, and opponents.

Remedial and Special Education

Computer games can play a role in remedial and special education. They can hold the attention of attention-deficit hyperactive children better than other approaches (39). Learning-disabled students with a negative attitude continue to practice longer using computer games compared with computer-assisted drill (40). If too pronounced, however, game elements may distract students from the learning task. Also, the game itself should be easy to learn and play. Finally, research is needed assessing whether frequent use of games reduces the likelihood that students will persist in a learning task when game elements are no longer present.

Designing Games

Guidelines on instructional game design for professionals are available (15,22,41). Briefly, developers should recognize the following:

- Game format does not guarantee the success of the game; rather, the challenge and enjoyment of a game and thus engagement in efficacious educational tasks is critical.
- High-quality sound and visuals are important for motivation and sustaining attention.
- The interface must be carefully planned; user control encourages students to take responsibility for their learning; resource-based learning allows pupils to explore and discover information; and interactivity supports investigative activities and maintains attention, making it capable of supporting complex conceptual learning.
- Games should include complete introduction of the task, structuring of the task, sequencing of component tasks, and meaningful feedback.
- Formative evaluation is an essential component of the design process.
- Instructional games should not stand alone. On-line help supports experimentation, but students working only on-line are less reflective. Thus, games should be combined with more reflective teaching methods.
- Teachers remain essential to ensure such reflection and the achievement of learning goals.

A different approach is to ask *students* to design games. Fourth-graders who designed computer games using the computer programming language Logo to teach third-graders learned more than a control group about computer programming and about the subject matter (42). They continued learning about programming past the end of the project, whereas the control group, who learned computer programming for its own sake, did not. Such learning took place in a setting of successfully creating complex software products designed for use by others.

Conclusions

Instructional computer games also have potential, albeit often unrealized potential. Educators who wish to use instructional computer games stand at a crossroads, facing three paths (43). Those traveling on the first use simple computer games for "rewards" or occasionally drill. They do not integrate computer work into their educational program. Those traveling on the second path integrate such structured games into their programs. Those traveling on the third path use simulations and problem-solving games. Research indicates that most use computers only occasionally, and usually only to provide "variety," "rewards," "enrichment," or "something for students to do" (44). Research suggests that the first path leads nowhere educationally useful. Teachers might better invest efforts and resources elsewhere. The second path is educationally plausible. Well-planned, integrated computer games can increase achievement in cost-effective ways. The third path is more challenging—in time, in effort, in commitment, and in vision. This path alone, however, offers the potential for substantive educational innovation.

FUTURE DIRECTIONS

Trying to predict the future of computer games is essentially a fruitless act. The technical advances over the last twenty to thirty years have been rapid, and it is likely to continue unabated for the foreseeable future. What can be said is that the push by developers is for content that is as complete a sensory experience as possible. A complete virtual world where the boundaries with reality are indistinguishable may only now be the stuff of science fiction. But it would appear that computer entertainment is moving in that direction, even if it never actually gets there.

Faster, Faster!

Obviously, some consumers can't seem to get enough. The demand is for faster action, higher animation frame rates, and more intensity. Game developers scramble to create the next big jump in game capabilities. Fortunately, the hardware manufacturers are able to feed this need by constantly pushing the capabilities of microchips to new levels. The game designers then quickly utilize every shred of computational power in the chips, which, of course, prompts the chip manufacturers to strengthen their offerings.

Virtual Reality

Virtual reality is one of those buzzwords often heard in computer magazines, the evening news, and even in casual conversation. It is actually something of an oxymoron, since if a reality is virtual then it isn't real. One might say that computer games generate virtual "surrealities." In fact, the flexibility of computers allows the imaginations of designers free reign to design completely surreal and even implausible environments. One goal of virtual reality is to make these environments so sensorially powerful that the user is completely lost in the virtual world. There is some speculation that such a complete experience will be psychologically dangerous for many individuals. Hence, there are actually ethical questions entering into the field of virtual reality.

The Internet

The Internet is beginning to have an extraordinary influence on PC games. The connectivity of the Internet allows users to play against opponents in geographically remote locations in real time. Perhaps the biggest innovation of the past few years is the proliferation of multiplayer games. Previously, games were confined to a single computer. But with networks, players can go online and compete head to head. This creates an exciting and dynamic gaming environment. As this technology merges with virtual reality, this will certainly increase the depth of the sensory experience.

A darker side of the Internet for game producers or any other software developer is the proliferation of illegal copies of their products. The ease of which programs can be duplicated and electronically distributed makes software piracy a major source of profit reduction. There is considerable effort being directed toward reducing this abuse of intellectual property. In addition, parents should monitor their childrens' participation in game-related Internet discussions.

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COMPUTER GRAPHICS. See THREE-DIMENSIONAL DISPLAYS.

COMPUTER HARDWARE AND SOFTWARE. See COMPUTER SELECTION.

COMPUTER–HUMAN INTERFACE. See INTERFACE DESIGN.