A Guide to Computer Games in Education for NASA

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For NASA's Office of the Chief Education Officer
Technology and Products Office
Program Executive

A mandate for NASA to leverage the power and popularity of games to inspire and educate

The Commission believes that great opportunities exist to engage the public through cutting edge multi-media products. *Moving images are to today's students what books were to students in generations past. Movies can bring technical space subjects to life for people who have no interest at all in mathematics or science. From IMAX films to Hollywood blockbusters, millions of space enthusiasts look to the big screen (and subsequent video distribution) for the latest in space "stories." The techniques employed by the film industry, applied to actual space science, can result in dynamic narratives that inspire and educate people.*

Similarly, video and simulation games are not only a multi-billion dollar industry; they are proving to be effective as learning devices for people of all ages*. Space flight simulators have long been used at the various NASA Centers, but only recently have similar programs been incorporated into smaller, hand-held "amusement" versions and made available for public use. The potential for converting hobbies and amusements to more educational pursuits is enormous.* ***NASA could collaborate with video game producers to create live-action learning modules that give players the chance to experiment with orbital mechanics, the principles of space flight, and other space-related subjects.*** *A new model for public engagement, which seeks broad grass roots support through coordinated efforts of government, industry, and non-profit institutions, uses professional communicators to formulate its messages, and* ***incorporates exciting multi-media products to infuse space exploration into our culture as never before.*** *Thus, such an effort is well aligned with the goals of the space exploration vision itself, which seeks to vastly expand our presence in space.**

From the *Report of the President's Commission on Implementation of United States Space Exploration Policy Moon, Mars and Beyond … A Journey to Inspire, Innovate, and Discover*, June 2004 (AKA The Aldridge Report): Recommendation 8.2.

*Emphasis added.

Executive Summary

Virtually all young people and more than a third of adults report playing computer and video games for entertainment. In terms of dollars, game sales rival Hollywood box office receipts. In terms of time, games are eroding the dominance of television in home entertainment. With the increasing popularity of games has come an increasingly strong call to tap into the power of games to engage players in order to inspire and educate. NASA and other government agency personnel will find themselves called upon to make decisions about how to use games to meet educational objectives. This guide has been created to provide the background necessary to make informed decisions regarding games.

The following are key findings resulting from the research for this guide:

- Games are accepted as legitimate educational tools by business and the military and growing numbers of academics and educators.

- Games promote greater knowledge retention than traditional forms of instruction. It is theorized that superior retention is the result of more complex understanding of material.

- The power of games to engage players is inherent in good game design. If game elements are sacrificed, value as an engagement tool will be eliminated.

- A full-scale, stand-alone or massive multiplayer online game will be necessary to have the kind of impact called for in the Aldridge Report.

This guide includes the reasons for considering games for educational purposes, a history of games in education, a review of the published literature on the topic and recommendations on how NASA can support the development of an educational game or games.

Human spaceflight is NASA's most dangerous endeavor. NASA has a long history of using simulations for astronaut training. Simulations with stated objectives to accomplish are, by definition, games. Clearly NASA recognizes that using simulations in this way is a powerful educational tool.

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Separating Games from Simulations

There has been much talk of games as educational tools in recent years. Most of it is speculative or argumentative, but very little of that talk is precise or carefully worded. It is part of our nature that we often engage in debate without first being sure we are using terms and phrases uniformly. Particularly on a topic where there is a recognized division between experts and novices, it is essential to spell out the use and meaning of what linguists would call the semiotic domain (discrete field with individualized usage or symbols and words that are clearly recognizable only to members of the affinity group of that field). It is easy to interchange the terms "game" and "simulation" when discussing educational uses of computers, because so often the two terms overlap. However, to the layperson who is not an insider (and indeed to the insider who has not specifically focused on the question) the issue of the difference between a game and a simulation can be a difficult one.

What is a game?

According to Clark Apt (1968), one of America's commercial educational simulation and gaming pioneers, a game is "any contest among adversaries (players) operating under constraints (rules) for an objective (winning, victory or pay-off)." This definition is hampered by the fact that it does not distinguish between contests for fun and contests of a more serious nature. Strictly applying Apt's definition of a game would mean that wars fought by combatants adhering to the Geneva Convention are games. While there may be philosophical arguments to be made about the nature of war and games, no one would seriously say that World War II and Monopoly belong in the same category. It is important therefore to add a clause noting that both educational and recreational games are low-stakes contests. Without such an inclusion, one of the fundamental advantages of games as educational tools- namely the opportunity for "soft" or low-stakes failure- becomes irrelevant.

If we accept the low-stakes modifier, we can constructively use Apt's definition to identify games. The definition has the merit of being brief at the expense of potentially sounding too narrow. With the strictest interpretation of "adversaries" as players, the definition would leave out all single player games and games where the players cooperate rather than compete. In a broader interpretation, the "contest among adversaries" can be seen as a contest between players, a contest between a player and the game itself or either of those types of contests with multiple players working cooperatively as a team. For an example using a recreational game, consider golf. A single player can compete against the rigors of the course alone to achieve a low score, two golfers might compete against each other for the lower score, or teams of golfers might compete against each other for the lowest score. It's possible that a single team of golfers could play against the course rather than each other, but it does not seem to be in the nature of golfers to play that way.

We are left with the definition that a game is a low-stakes contest with rules and the goal of "winning" the contest.

What is a simulation?

Harold Guetzkow (1963), widely regarded as one of the founders of simulation studies, defines simulation as “an operating representation of a central feature of reality”. Leaving aside for the moment the issue of whether or not there can be a simulation of a thing that does not exist, Guetzkow’s definition clearly asserts that operation is a key element of simulation. Bloomer (1973) pointed out that the “operating” requirement neatly removed static representations such as maps, pictures and diagrams from the category of simulation. This can be a very fine distinction in an era when cheap computing power makes three-dimensional models relatively simple to create. By Guetzkow’s definition, a three-dimensional image of a human body is not a simulation, but such a model that allowed a viewer to manipulate or drive biological functions would be a simulation.

Under the Guetzkow definition, there cannot be a simulation of something that is not real. A three-dimensional model of a unicorn with the ability for the user to manipulate biological functions exactly like the simulation of the human body in the last example would be a clever model but would not be a simulation.

A simulation is an operational model that is based on something real.

Games, Simulations and Simulation Games

Reviewing the definitions for game and simulation, it is clear that each can stand-alone. In addition, there is a sizeable field of games that are simulations, or perhaps simulations that are games. Such a combination would be defined as a low-stakes contest with rules with or in an operating model of a real thing. Carrying on the example of a simulation, a three-dimensional, operating model of a human body might be used for a game where the player has to manipulate caloric intake and metabolic rate to achieve and maintain a target health level. *Oregon Trail* is an example of a simulation game. It is a functioning model of a wagon train in which the player strives to get families safely to Oregon. The figure below shows the relationship of computer games and simulations.

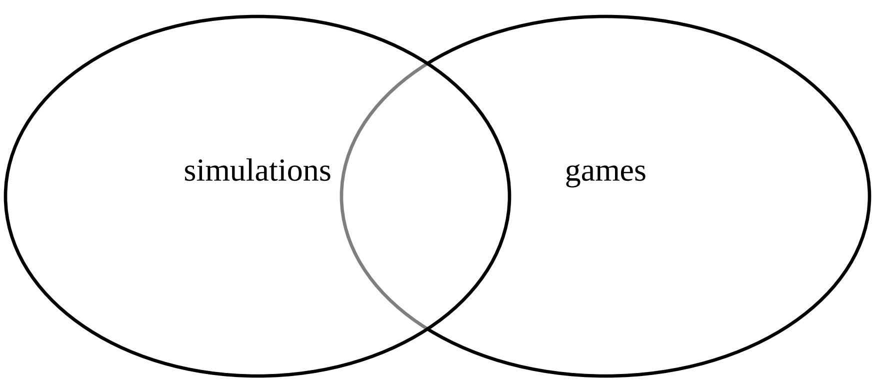

Figure 1: Games and simulations overlap (Ellington, 1981).

Game Platforms

At least one difficulty is inherent in trying to understand the impact of computer games as educational media. The term *computer games* is being used to cover the entire realm of computer and video games as if there were some convenient way to make all computer games equivalent to allow a simple black and white assessment. To the uninitiated, lumping all computer and video games together in one category is a simple assumption. To the informed investigator, it is similar to lumping carryout restaurant menus, textbooks and the collected works of Shakespeare into the category of *printed text* and asking the research question, "what is the impact of printed text on education?" Even in a heavily researched field, a broad enough generalization in a question can make it impossible to produce a meaningful answer. The area of the educational use of computer games is not a heavily researched field. It has only recently immerged as a legitimate area for serious research. There are some who still do not take the work of computer games researchers seriously. The many different kinds of games, various potential uses and differing research methods and objectives make it difficult to draw simple, comprehensive conclusions about the impact of computer games in education.

In much of the recent literature the terms *computer games, video games* and *games* are used interchangeably to describe the array of electronic games. The terms are convenient shorthand when speaking generally about electronic games. There are, however, inherent problems when considering a diverse range of media as if all the subsets were identical. For the purposes of this paper, the terms *games* or *computer games* are used generically to cover all forms of electronic games. When specificity is needed, the games in question will be precisely identified by their platform or the term *traditional games* in the case of non-electronic games.

PC Games

The personal computer is one of the most popular platforms for playing games. According to the Entertainment Software Association (ESA, 2004), 50% of games sold in 2004 were PC games. Virtually all PC games are developed to be played on Windows operating systems because Windows is the dominant operating system in the personal computer marketplace. Many games are simultaneously released in Macintosh compatible format. It is not common practice to release commercial games specifically for either Linux or Unix operating system. PC games are the dominant game of choice among players over 18, but are used by players of all ages (ESA, 2004).

Console Games

Game consoles date back to the release of the first Atari systems in 1977. These dedicated computer systems plug into a television and are played through controller pads. They are most popular with younger gamers, but used by players of all ages (ESA 2004). The current popular console systems are Sony's Play Station 2 (PS2), Microsoft's X-Box and Nintendo's Game Cube. Like the original Atari system, these consoles use a television as the playing screen and are played through handheld control paddles. The console itself houses the dedicated computing system that runs the game. Just like personal computers, the processing power, memory and graphics capabilities of the systems have improved dramatically since the 1970s. Also like personal computers, consoles have shifted to a compact or digital videodisc format for games.

Cell Phone Games

Cell phone games come in two varieties. There are the traditional varieties of video games that can be played on the cell phone screen itself. Such games are either loaded into the phone as a feature or can be downloaded after purchase. These games are advertised as entertainment specifically to be used during "down time" when the phone owner would otherwise be bored but is not free to seek a more robust distraction. The other variety is of cell phone game is one of the several activities to be dubbed *augmented reality*. In this type of game, the cell phone is a conduit through which the player interacts with other players remotely. Rather than playing a game on the screen, the players are engaged in some form of physical activity in the world around them. Scavenger hunts using the picture taking capabilities of many cell phones have been a popular form of augmented reality game.

Handheld Games

The category of handheld video games includes games played on handheld computers like the Palm or Blackberry, portable gaming systems like the Game Boy line and dedicated devices that play only one preset game. Mattel's electronics division produced a number of such single-game handhelds in 1970s and 1980s. While less expensive, single-game devices were not able to effectively compete against the cartridge-based systems that allow players to play different games on one device. Soloway (2001) has argued that the power of handheld computers is to draw children into learning precisely because those devices are similar to handheld game systems. However, there is not yet a collection of compelling games that is drawing players to palmtop computers as recreational devices. That role is still firmly held by dedicated game systems like Nintendo's Game Boy and Sony's Play Station Portablel.

Modes of Play

Single-Player

The basic computer game unit is one player playing on one platform. Historically the majority of video games have been designed with single player experience in mind. Many games do not allow for any other mode of play. Whether sitting at a computer or carrying a handheld system or hooking a console to a television; one individual playing with one machine is the most common game playing situation. Games like *Civilization*, *Tetris* and *Solitaire* were originally developed with a single player in mind.

Multiplayer (Head-to-Head or Cooperative)

While PCs and handheld games have traditionally been designed with a single player's experience in mind; console games have a strong history of multiplayer modality. The first commercially distributed console game, Pong, was meant to be a head-to-head playing experience between two people. All game consoles are manufactured with multiple controller ports so more than one player can play at a time. PCs and handhelds, traditionally, do not have any way for a second player to use the system at the same time as the first player. PC users are able to link their computers to a network or the Internet to play games with other players running the same games on their systems. The recent versions of the Game Boy have the ability to network with units of the same model. Console systems allow up to four players to play simultaneously through the same console. The latest generation of game consoles has the capability to link to the Internet.

Hot-Seat

One of the less popular ways to play a multiplayer game is known as "hot-seating". In this arrangement, players take turns at the game controls. Before networking was an easy and common option for personal computer owners, this mode of play was built in to many games. In the popular space game *Master of Orion*, players could take turns sitting at the keyboard and guiding their galactic empire. As each human player completed all of their actions, resolved combats and allocated resources for the round, they would vacate the seat in front of the keyboard for the next player. When all the human players had finished, the computer would plot the actions, resolutions and resources for the automated players, then process all of the events for that round. The next round would begin with the first player taking the "hot-seat" at the keyboard. The process would continue until the end of the game. Because hot-seating literally multiplies the length of game play by the number of human players, this type of multiplayer game could take several times as long to play as the single player version.

It is worth noting that hot-seating provides a very different social experience than the other more popular and common forms of multiplayer game. The turn-based play is similar to that in most board games; however, the time each player's turn takes is usually much longer than what would be experienced in a traditional board game like *Monopoly*. While all multiplayer games are social by nature, the hot-seated games provide enforced time when one or more players are not actively engaged in playing the game. With three or more players playing, the result is a natural period for socializing while not playing. In other multiplayer game modes, constant engagement in the game for all players means a conscious decision to socialize would have to be made.

Network

Network games allow multiple players to play a single game simultaneously. The computers must be networked together, but the game may run either on a server on the network or through peer-to-peer connection. This type of game has given rise to the phenomenon of LAN parties where groups of players gather physically to network their computers and play games together. *Counter Strike*, *Battlefield 1942* and *Medal of Honor* are all games designed for a network experience. While most network games can be played in stand-alone mode, the design anticipates the idea that networked play enhances the quality of the playing experience. The line between network and stand-alone games has become blurred as many stand-alone games have been designed with the option to network. Most games, however, are marketed primarily to one mode or the other.

Online

Online games are a subset of networked games but have sufficient distinct characteristics to be treated as a separate type of game. Virtually all networked games can be played over the Internet. If more than a few players are going to successfully play together, the game will have to run on a server rather in peer-to-peer mode. Some games are designed exclusively for online play. Online games tend to require a client-server structure, but those with only a few players can be peer-to-peer.

Massively Multiplayer

At the opposite end of the games spectrum from the single stand-alone game is the massive multiplayer online game (MMOG). The division between a standard multiplayer game and an MMOG is several orders of magnitude. Conventional multiplayer games are those that allow anything from two to 64 players to play the same instance of a game. MMOGs have the capability for thousands of players to play the same instance of a game simultaneously. They are designed to be played exclusively online. *Everquest*, *Lineage* and *Dark Age of Camelot* are a few examples of this class of game. For perspective, at its high point, Sony claimed that as many as 150,000 players were logged on to *Everquest's* thirty servers at the same time. That's an average of 5000 players per server all playing in the same instance of the *Everquest* world, Norrath, at once.

MMOGs are different than other networked games. They are persistent, virtual worlds. Single player and most networked games are usually replayable, one-story games. The play or players start the game and then play it to a conclusion in either one or multiple sittings. Afterward the game is turned off. Future uses of the game start over from the beginning or replay from a saved version of a previous game. MMOGs do not end. Players login and logout while the game world continues to run on the servers. Players can advance and improve in the game, but while they can have many victories, players do not win or lose an MMOG. They win or lose over and over again inside the MMOG. In traditional computer games, the game itself is the play space for the action of the game. Usually there is little more to the game world than what the player or players see on their way to winning. In a MMOG, there is a wide virtual world in which game play happens. Players move about the virtual geography on their way to and from adventures. They are literally playing inside the game world rather than playing a single game. Pioneering games researcher, Edward Castronova (2005) has dubbed these persistent, virtual, play spaces *synthetic worlds*. Character interaction is a vital part of MMOGs.

Game Software Architecture

Application Games

These are the full-scale games that are usually distributed on CDs or DVDs or game cartridges. They are the traditional products of the commercial games industry. While size and scope can vary, the higher end versions of these games tend to require tens of hours to complete or master. Blizzard, Firaxis and Microsoft all develop and distribute these types of games.

Client-Server Games

Related to the application games are client-server games. In these networked games, the player runs a copy of the game on their local system while another copy runs on a server. The player's client copy communicates the player's actions to the server over a network or the Internet. The server coordinates the information transmitted by a number of clients and sends updates to all the connected clients. This linked play allows multiple players to interact with each other while each is playing from a different computer.

Browser Games

Browser games are applets played in Web browsers. They are structurally simpler than contemporary stand-alone games. They are usually programmed in Flash or Java. These games tend to be designed to allow completion of play in as little as a few minutes. They are widely distributed online and find common use in filling (or distracting) time between other tasks. Yahoo Games is a well know source of browser games. Browser versions of chess, pool, word and puzzle games illustrate the range of this form of game. Many browser games are available free of charge. Premium browser games, however, often have to be purchased from the host website.

Game Genres

Computer games, like books and television shows, come in a number of different genres. The literature offers several different efforts to categorize those genres. In Figure 2 is one such effort taken from the British Education Communications and Technology Agency (BECTA). While there is some variation between sources, all of the catalogs look similar to this table with minor variations on the number and names of game genres. It is important to note that the use of the term genre here refers to the play structure of the games and not the setting of the game. The genres should be considered with games in any setting. The distinction here is about the structure of the game in regards to rewards, rules and advancement. Sometimes the lines between genres can be blurry. There are many games that fit into more than one genre. For example, the game *Tomb Raider* is both an action and adventure game because of the combat, exploration and problem solving elements, and a role playing game because the player is developing the Lara Croft character as they play.

Genre	**Examples**	**Description**
Action adventure	Tomb Raider, Soul Reaver	Combines elements of combat, platform games, problem solving and exploration.
Fighting games (beat'-em-ups)	Tekken 3, WWF	Most popular on consoles, game play is based on two or more opponents attempting to knock the other out.
Management games	Championship Manager 2001-2002, City Trader, Zoo Tycoon	Usually based on economic management in a simulated environment. The player must raise funds to pay for maintenance, wages, research, a new striker, etc. They can be very complex and a single game (or 'career') can continue indefinitely.
Platform games	Rayman, Lego Alpha Team, Abe's Odyssey	The player must complete levels by avoiding various obstacles, jumping onto platforms or using objects with special properties (trampolines, ropes, etc).
Racing games	Grand Turismo 3, Wip3out, Grand Prix 3	The realism of racing games can vary from approximate simulations of rallies using real map data, to arcade-style races, where realism is sacrificed to provide a greater sense of speed and present feats of driving impossible in reality.
Real time strategy (RTS)	Command and Conquer, Sudden Strike, Stronghold	The player will normally command groups of units and gather resources to fund further expansion. Units move in 'real time' synchronous with the opposition's units. Games are usually themed around warfare or empire building by conquest. The imagery and level of violence can vary greatly.
Role playing games (RPG)	Fallout, Baldur's Gate	The player controls a single character or group of characters. Game play is usually based around exploration and completion of quests.

		There may be elements of fighting, but there are often many ways around each situation.
Simulation games	IL2 Sturmovik, Train Simulator, Flight Unlimited	Simulation games can provide very accurate reconstructions of modern or historical vehicles. Such games are usually rated by their accuracy and complexity, although options are normally included to simplify the simulation.
World-building games / 'God' games	*SimCity*3000, Civilisation 3, Black and White, The Sims	This category covers a wide range of game styles (some may also be called simulations). Essentially, the player must manipulate either a character or an environment to encourage development and progress. The game's objectives may be open-ended; the attraction is often in 'tinkering' with environments. Combat rarely features in games of this type

Figure 2: From the British Education Communications and Technology Agency's advice to teachers website http://www.ictadvice.org.uk.

As noted earlier, there is a distinction to be made between simulations and games, but there is also an overlap body of simulation games. The identification of that class of games in this table should not be misconstrued as a claim that all simulations are inherently games.

Graphic versus Text-based

In the early days of personal computing, many games played on PCs were text-based. Games might have had accompanying graphics, or they might not, but the images were static. The action of the game came from players either selecting between text choices on the screen or from players typing in text commands. The earliest online games were played over bulletin board servers (BBS) and were, like PC games at the time, necessarily text-based. The early computer game players tended to be fairly technically oriented. After all, in the late 1970s and early 1980's, most people who owned and used computers were more technologically literate than the average computer user today. The environment those users worked and learned in was text-based so, it was only natural that their recreational activity on the computer be in the familiar text style. Chances are, individuals who have not played a computer game since the early 1980s, remember computer games as text scripts rich in description with branching choices for players to make.

With the development of the Macintosh graphical user interface, games with more screen action and less text began expanding in popularity. It was not the interface as much as the increasing computing power of systems that drove the trend. By the early 1990s, text-based games had become a minority share of the games market. Graphics quality became nearly synonymous with game quality. Game reviews often carried lines like "the game has great graphics, but the storyline is weak," so a game might still receive a good rating on the weight of the visual appeal. On the other hand, it was rare in the extreme to find a highly rated game that did not have topnotch graphics. This is not to say that PC games abandoned text. Many PC games have rich dialog, background stories and an abundance of informative text. However, the action is almost always based on interacting through graphic icons in a graphic environment. A text-based PC game would not thrive in the modern gaming arena.

Console games can trace their modal heritage back to arcade games. In fact, *Pong* was first released in 1971 as an arcade style upright system with a built in monitor (Kent, 2001). It was installed in game arcades and other venues like hotels and bars very much like pinball machines had been for decades. Like all arcade games, Pong focused on direct control of in-game action by the player. There was no text beyond the promotional splash screen, score keeping and the credits screen. Working the simple control panel drove all the action. The control paddles of today's console games are still basic modifications on the traditional arcade game control panel. The games for console games remain heavily action oriented despite the addition of a plug in keyboard option for some consoles.

History of Computer Games in Education

History of Games

The first documented use of games for educational purposes dates to mid-1800s when the Prussian army started training officers by having them play simulated battles on printed maps with detailed rules (Brewster, 2002). Prussia was among the first nations to develop a modern professional military with formal training for officers. War games permitted officers to gain martial experience in low-stakes contests. In 1879, the US Army adopted tabletop war games as a training tool. The US Navy followed suit in 1894 (Lee, 1990). For nearly the next 100 years, professionally produced educational games remained almost exclusively the domain of the military and military enthusiasts.

In the 1950s, an emphasis on improving and professionalizing business management led to the first non-military application of games. The American Management Association published the first business game in 1956 (Riccardi, 1957). It was a simple simulation game where players took on the role of a manager attempting to navigate their way to success while being confronted with a variety of events and challenges. Games, simulations and case studies quickly became popular management training tools. They provided a bridge between theories taught using textbooks in classrooms and real world business experience.

Games have long been part of the educational arsenal of schools. Plato praised Egyptian educators for their use of games to provide learning experiences though he did not provide many details (Brewster, 2002). Spelling bees have been a long-standing feature of American education. Laura Ingalls Wilder (1953) reported competing in such a contest during her schooling in the late 1800s. While both the military and business applications of games had educational goals, it was not until the 1960s that professionally published games entered the K-12 classroom (Ellington, 1981). Board, card and role-playing games for schools were all being published for American schools by the early 1970s.

History of Computers and Consoles

Through the 1960s, only three universities in the US had computers with monitors (Kent, 2001). Computers were large devices restricted to military, corporate and intensive academic use because of their cost and technical requirements. In the 1970s, as computer technology became smaller, less expensive and more user-friendly, computers began to appear in schools. At the same time, companies like Zenith, Atari and Sega began selling the first game consoles. Console units attached to a television and allowed users to play interactive games on their television sets.

In 1977, Apple Computer began selling the first home computer (a term replacing microcomputer for the smaller machines of the time), the Apple II. Tandy, Radio Shack and Commodore followed suit the same year. Atari released a home computer in 1979, and in 1981, IBM entered the home computer market with the system that would eventually give its name to all desktop computers: the PC (for personal computer).

Games on Computers

Consoles were invented to play games on televisions. While they are, in fact, dedicated computer systems, they have not had an independent existence aside from their role as game machines.

The earliest computer games were a tennis game for an oscilloscope and *Spacewar*. The tennis game was a one-time novelty invention that had no successors or follow-on. *Spacewar*, however, influenced the early years of computer game development and went on to be revised and released as a console game, an arcade game and, eventually, a personal computer game (Kent, 2001).

The Apple II firmly established Apple as the dominant classroom computer in the early 1980s. It would not be until 2003 that Dell would sell more Wintel computers to schools than Apple sold Macs in a single year. While the last member of the Apple II family- the Apple II c Plus- was rolled out in 1988, the company continued to support the line through 1993 because so many schools were still using them (Weyhrich, 2005).

The First Wave: Simple Games

The first educational computer games were simple fare. These games were designed by Atari's in house programmers. They were more about the ability of designers to show that systems had potential educational uses than about creating good educational products.

Basic Math (1977) for the Atari 2600.

Atari advertised this cartridge as a game. It put simple math problems on the television screen and let the player select the answer one digit at a time. There was no score and only single player mode, so this was not truly a game.

Brain Game (1978) for the Atari 2600.

This game was a little more sophisticated than the *Basic Math* game released for the Atari 2600 a year earlier. The *Brain Game* offered nineteen different activities including addition and memory games. This game had scores but only single player mode. It was a very limited form of an educational game.

Figure 3: Atari's *Basic Math*.

The Second Wave: Educators Get Involved

These games were an advance over the simple games of the First Wave. They are the product of educators and programmers working together. For the first time applications really have both educational and game elements recognizable in them. Since game systems were not widely adopted in schools and computers were, the *Chemical Element Game* was the first educational computer game to have a chance of being adopted in schools. Game console games in this era were almost entirely home systems, so games for those systems were mainly intended for use outside of schools.

Chemical Element Game (1978) for computers that could run BASIC.

The *Chemical Element Game* challenged players to compete against each other or the game as they attempted to guess elements and compounds based on clues about their properties. Players earned more points the fewer hints they used. The game used only 34 of the chemical elements. The game was developed specifically to be used with the British chemistry curriculum in consultation with university chemists (Ellington, 1984).

The Electric Company's Math Fun (1979) and ***Word Fun*** (1980) games for the Intellivision system.

This set of games was a collaborative effort between the Children's Television Workshop and Mattel. This merger of educational and games expertise was unusual and noteworthy. The Intellivision game system had much better graphic capability than either its Coleco or Atari rivals, and these games reflected that. In Math Fun, one or two players advanced gorilla avatars through a jungle by successfully answering simple math problems posed by various other animals. *Word Fun* was the more sophisticated of the two games. Players had a choice of playing a crossword game, doing a word search by maneuvering a monkey to catch letters in a jungle or using rockets to fire vowels into lines of letters with blanks to make words. The activities in these cartridges were all scored with rules and competition, making them real games.

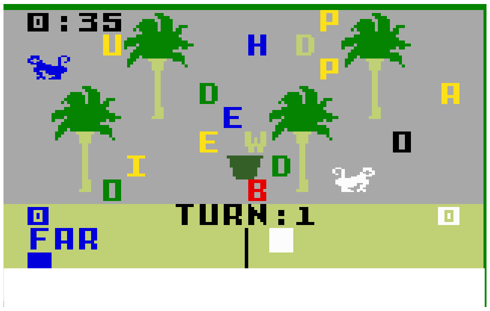

Figure 4: Mattel's *Word Fun*

The Third Wave: Rise of the Educational Software Companies

The increased computer power and popularity of the later Apple II line allowed for richer, more complex games. The Apple IIe became the gaming industry's programming standard from shortly after its release in 1983 until the mid 1990s. For the first time, educational games could take advantage of increased computing power to let the machine do some of the more onerous chores involved in educational simulation games. One weakness of manual simulation games was the time involved in learning and managing complex rules. Using computers, a player no longer has to give up learning/playing time to master a rules system. The computer can take care of the administrative elements that previously required efforts from a referee or the players themselves.

Earlier educational computer games were the products of general video games or traditional games companies. In 1982, The Learning Company (TLC) became the first dedicated educational software company (Kent, 2001). TLC would release some of the most popular educational software ever. In a survey of educational computer games conducted by Education World in 2001, TLC games took three of the top four rankings (Starr, 2001). Since the mid 1980s, virtually all successful educational computer games have been developed or released by educational software companies or educational units of major software companies.

Oregon Trail (1985) for the Apple II.

Figure 5: TLC's *Oregon Trail*

Oregon Trail was initially developed by the Minnesota Educational Computing Consortium (MECC) as a text-based game for teleprinters linked to macrocomputers. The Learning Company handled the commercial releases of this and other MECC games before ultimately purchasing MECC in 1987. After the commercial release of *Oregon Trail* in 1985, it became the first educational game to be widely adopted by schools. In *Oregon Trail*, the player guided a simulated 1848 wagon train from St. Louis to Oregon. Along the way the party faced hardships and obstacles that gave the player an intimate understanding of the Western Expansion movement. Though no score was given in the game, success was judged on whether or not the wagon trained reached the intended destination.

The following assessment offered by one of the editors of the online Game Museum neatly captures the sentiments of generation x and y students who experienced *Oregon Trail* and other MECC games in school.

> Back in the early 80's …educational software quality ranged from "programmed in two minutes and only teaches kids that eating snow is more entertaining than computer games" to "not horrible." Only a few really stood out as being **really**

popular with the kiddies, and most of them were MECC games. (Fragmaster, 2005)

Where in the world is Carmen San Diego (1985) for Apple II and DOS.

This was the first in a series of *Carmen San Diego* games. Broderbund released it in 1985. Broderbund was another commercial educational software company. It eventually bought The Learning Company in the mid 1990s. In this game, players took the role of detectives working for the Acme agency. They followed clues and learned geography, culture and history in order to track down the infamous Carmen San Diego. The game was popular in both homes and schools. It spawned a host of branded merchandise and a Saturday morning cartoon series of the same name. In a survey of educational computer games conducted by Education World in 2001, *Where in the world is Carmen San Diego* was ranked as the third most popular educational game of all time (Starr, 2001). Because of the nature of the game, it was easy for the parents and teachers to accept that children were learning material relevant to their regular school curriculum when playing this game.

Reader Rabbit (1989) for DOS.

The *Reader Rabbit* series from The Learning Company was stylistically a successor to *The Electric Company's Word Fun* game. It had word games with scores and timers and was designed for young children learning to read. It is a good example of the genre of developmental games tailored primarily to home audiences as a supplement or forerunner to formal education.

The Fourth Wave: Into Virtual Worlds

Until the 1992 release of *Wolfenstein 3D* by Activision, computer and console games were designed with a top-down, two-dimensional (flat) look and feel. *Wolfenstein 3D* was the first game to simulate three dimensions to increase the players sense of immersion in the game. It was also the first home version of a game genre called "first-person-shooter" (fps) that became and remains wildly popular with computer game players (Kent, 2001). In fps games, the player typically views the virtual world from the perspective of their avatar while they move through the environment. Some earlier games made use of simulated three-dimensional static images, but *Wolfenstein 3D* was the first to let players maneuver through, manipulate and interact with the setting. While *Wolfenstein 3D* was not an educational game, it paved the way for educational games to make use of much more complex virtual environments. The benchmark for immersive graphics for the 1990s was *Myst*. The impressive visuals in that immersive mystery game attracted new players to computer games. It was not until 1997 that a successful educational game was released that took advantage of the immersive potential of 3D graphics.

Figure 6: Broderbund's *Myst*

Oregon Trail III (1997) for Windows.

This was the third remake of the first widely successful educational computer game to be adopted by schools. The game was very similar to the original version with improved graphics and a substantial first-person perspective design. It is noteworthy that this version of *Oregon Trail* was released first for Windows and only a year later for the Mac. It probably reflects overall dominance of the computer market by Wintel machines, despite the continued popularity of Apple systems in schools. There is no evidence to show that players got more out of the immersive version of *Oregon Trail* than they did the 2D version, but each was on par with the non-educational games of their time.

Physicus (1999), ***Bioscopia*** (2001) and ***Chemicus*** (2002) for Windows.

These completely immersive, science-rich games were released in the US by Tivola Publishing, but developed in Germany by Ruske and Puhretmaier Edutainment Company. These three titles were full-scale games with state-of-the-art 3D graphics. They had engaging storylines and required the player to unravel mysteries to eventually triumph over adversity and win the game. They were completely Myst-style games with the twist that the player had to use real science to win the game. The subtitles of two of the games reflect the spirit of the series: *Physicus: Save the world with science!* And *Bioscopia: Where science conquers evils!* These games stood out as notable successes in the field of educational games where traditional *edutainment* fair has been neither particularly entertaining nor significantly educational (Kirriemuir, 2002). Unfortunately, the list of educational games that rise to the level of quality of these games is not a long one even three years after *Chemicus* was released.

Mainstream Games in the Classroom

To take advantage of the power and popularity of games, some teachers have adapted mainstream games to educational purposes. Documented cases are rare, and what little research there is on the subject suggests that such usage is almost entirely for research purposes rather than genuine adoption into the classroom (Kirriemuir, 2002). Nevertheless, the adaptation of mainstream games is worthy of inclusion in the Fourth Wave, perhaps more for its potential than its practice to date. While educational games can have an impact on learning whether they are used in the home or in the classroom, adaptations of mainstream games tend to be used only in the classroom or as assigned by a teacher.

SimCity (1989) for all computer platforms.

SimCity was probably the first mainstream game to be used in classrooms. It is certainly the most researched case (Frye, 1996). Players directed the development of a model city. The game was a blockbuster hit and has led to an entire family of Sim games including the biggest selling game ever, *The Sims*. Maxis did not intend the game to be used in schools, but teachers and graduate students have developed a substantial body of material to support classroom use of the game (Pahl, 1991). In classes including Social Studies, English, History and Economics, teachers have used versions of *SimCity* to improve student understanding and retention (Frye, 1996). It is likely that no other mainstream game has received so much in-class time and attention.

Civilization III (2001) for Windows and Mac.

This game was the third installment in Sid Meier's extremely popular *Civilization* series. The player attempted to guide their chosen civilization to global dominance over the course of 6000 years. This game is part of the strategy game genre. Like many modern games, *Civilization III* allows players to design their own custom scenarios for the game. Game companies encourage the development and sharing of scenarios as a way to increase the replay appeal of their games. *Civilization III* has been used experimentally as a classroom tool with customized scenarios to guide students' experiences (Squires, 2001).

Figure 7: *Civilization III*

Doom (1993) for Windows and Mac

Doom was a very popular example of the first-person-shooter genre. In the game, players moved through a multi-storied facility battling monsters and searching for gear to heal themselves and enhance their killing power. Inspired by students' (and his own) love of computer games, one instructor at West Point developed a modified *Doom* scenario as a quiz tool for his class (Carver, 1997). Students moved through a structure encountering quiz questions. If they answered correctly they received ammunition and healing, if they were incorrect, the question turned into a monster that had to be destroyed. Getting three incorrect answers out of twenty on the same floor forced students to restart that floor. Carver (1997) noted that increased time spent on quiz preparation and that some student requested time outside of class to improve their scores even though they passed the quiz in class. Developing the *Doom*-based quiz tool took 200 hours. That may explain why there are not many similar uses of games reported.

There remains much to be written about the full history of computer games in education and even more to be written of their future. In sketching a brief history, this paper offers a framework from which to flesh out a more complete history. It also provides a pattern for ordering what has traditionally been a bit of a chaotic jumble. The "Four Waves of Educational Computer Games" framework is a conceptual demarcation to better enable meaningful examination of the historical role and impact of this popular medium on modern education. In the current debate about the future role of games inside and outside the classroom, it is easy to forget that they have a longer history than the current spate of research literature. It seems likely that educational computer games modeled on those of the Second and Third Wave will continue to dominate the educational games market for the foreseeable future. They are simple, basic and tremendously less expensive to develop than games in the style of the Fourth Wave (Kirriemuir, 2002). It will take the efforts of both educators and game designers to realize the full potential of computer games as educational tools. It will take an awareness of their history to guide their future.

The Existing Research

There is a division between two communities of research on the educational use of games. The older community can trace its roots to the earliest use of simulations and games in the area of business management training in the 1950s (Butler, Markulis and Strang, 1988). This community tends not to differentiate between games and simulations and tends to focus on their use for training management professionals. Having roots much older than the first personal computers, this community tends not to distinguish between computer and non-computer-based activities. The main publishing venue for this community is the *Journal of Simulation & Gaming* (Leemkuil, De Jon and Ootes, 2000). According to Dorn (1989), this community has been in decline since the early 1980s.

The other community has roots dating to the early 1980s, but really began to flourish around the turn of the millennium (Simon Egenfeldt-Nielsen, 2004). This community focuses exclusively on computer games to the exclusion of simulations unless the simulations happen to be games in the simulation genre. The computer games research community has several publishing venues including the *Journal of Game Design*, *Games Research* and *Game Studies* and boasts several professional organizations and a growing number of annual international conferences. There is very little connection between the communities in the relevant research literature (Egenfeldt-Nielsen, 2004**)**. Computer games researchers tend not to consider the early work of simulation and games researchers. This state of affairs was neatly, if somewhat peevishly summarized by an anonymous poster to a games research discussion board that said, "It's like they (computer games researchers) think games research began with the Internet." The review of literature that follows (as is true of this entire work) proceeds from the assumption that the division between the two communities is unhelpful and continues to diminish the potential of both communities. This work presupposes that research and theory that have gone into considering non-computer games in education can be applied profitably to computer games in education. Wiebe and Martin (1994) compared a traditional game to a computer game for teaching geography and found no statistical difference in motivation, interest or learning outcomes.

Pre-computer studies

Pierfy (1977) reviewed twenty-two comparative simulation games studies. The aggregate result was that simulations and games were no better or worse as learning tools than conventional classroom methods of teaching. The studies did indicate that students had a more positive attitude about games and simulation than they had about traditional instruction. There was also an indication that long-term retention of material was greater with games and simulations. Pierfy (1977) also found that simulation games were superior to traditional teaching in the area of changing student attitudes about the subject material. This is likely a result of coaxing students to spend time regarding subject material from a perspective differing from their pre-existing beliefs. Laughlin (2001) found that even a brief period of pretending to hold beliefs had a mitigating effect on established attitudes. The research theorized that time spent considering material while pretending to have a different perspective expanded individuals existing mental models and tended to result in a more complex understanding of the subject. A more complex mental model opens individuals to viewing evidence in a less biased fashion and tends to have an ameliorating effect on polarized attitudes.

Pate and Majeta (1979) reviewed earlier games and simulation studies searching for those dealing with long-term retention. Typical for researchers of the time, they do not differentiate between games and simulations. They noted Pierfy's (1977) result that retention was one of the areas where a difference could be seen between conventional teaching methods and classes using games or simulations. Using a minimum of a two-week time delay between an initial post-test and a post-test to evaluate retention, the pair found eighteen studies included retention (Pate and Majeta, 1979). Every one of the studies that examine retention found that students using simulation games had a statistically higher level of retention at least two weeks after treatment than students who covered the same material with traditional teaching methods. In several cases, students who had used simulations or games scored significantly higher on the retention test than they had on the original post-test (Karlin, 1971; Cohen, and Bradley, 1978; Lucas, Postma and Thompson, 1975). This result seems to support the theory that games and simulations enable student to absorb complex mental models that facilitate further learning about the subject of the model. In contrast, traditional teaching methods tend to transmit knowledge as discrete bits of data without a framework to facilitate expansion of understanding. Dickerson (1975) also studied to see if games induced higher levels of retention over traditional classroom activities. Games were found to lead to greater retention than traditional instruction.

The most consistent finding about games as educational media in the pre-computer game studies was that students preferred games to any of the alternatives offered at all grade levels (Livingston, 1970). Even when students claimed that they preferred case studies, for instance, monitoring of attendance, usage and discussion indicated voluntary selection of games over case studies (Anderson, 1964). Several studies also indicate that games and simulation were particularly effective in motivating students who were typically disinterested in school work and not working to their potential (Apt, 1970).

Computer games studies

One of the reasons often given for the use of computer games for education is that the medium itself will provoke greater interest in subject matter than traditional instruction. The commonly stated assumption is that greater interest leads to spending more time on task, which in turn results in increased learning (Gee, 2003). Malouf (1987) evaluated the levels of motivation of subjects playing educational computer games compared to those receiving traditional instruction. The study found that computer games led to significantly increased levels of ongoing motivation. This study did not attempt to assess whether games were a superior learning tool in general. If the previously stated assumption about time on task leading to enhanced learning is accepted, Malouf's work takes on greater significance because it implies users of games are motivated to spend more time on task. Whether and when motivation actually leads to more time spent on task was not within the scope of the study.

Malone (1980) researched the issue of how to make more enjoyable educational computer programs. As has been stated elsewhere, *edutainment* has largely failed to meet the hope of making fun and educational games. Malone sought to identify the characteristics of successful computer games to enhance the calibre of educational computer games. Malone's (1980) main consideration was intrinsic motivation defined as what makes an activity rewarding in its own right rather than through external rewards. Initially he considered the areas of challenge, fantasy, and curiosity (Malone, 1980). He later expanded his categories to include control and interpersonal motivations (Malone & Lepper, 1987a).

- **Challenge**: The activity should be of appropriate difficulty level for the player. This is done through clear both short-term and long-term goals, uncertain outcome, and facilitating investment of self-esteem through meaningful goals. Furthermore clear, constructive, encouraging feedback is essential.
- **Curiosity**: The information in the game should be complex and unknown as to encourage exploration and organization of the information both in relation to the sensory area and the cognitive area.
- **Control**: The player should gain the overall feeling of being the controlling party. This is done through a responsive environment, high degree of choice in the environment, and by equipping the player with the ability to perform great effects.
- **Fantasy**: The activity can increase intrinsic motivation by using fantasies as a part of the game universe. These should appeal to the target group emotionally, serve as metaphors for the learning content, and be an endogenous part of the learning material.
- **Interpersonal motivations**: This refers to the increased motivation resulting from the social context of the computer game most directly competition and collaboration with peers. Also the recognition of your peers will serve to motivate.

Malone & Lepper (1987a) condemned educational computer games that used game elements only as a reward for doing some traditional educational task in the game. They argue that such extrinsic rewards were poor motivators. With a strong belief that intrinsic motivators were the only powerful form of motivator, the team argued for better designed games where succeeding was a reward itself rather than a key that unlocked some external rewards. Malone & Lepper (1987b) identified several areas for further research that are still unresolved. One issue is how to balance the wish for learning specific content, attitudes, or skills with the discovery-based and motivating approach advocated by constructivist learning theory. This question plagues all forms of instruction but is particularly applicable when considering the potential exploration opportunities in computer-based learning environments. They also raised questions about how to appropriately deal with difference in learning style, academic ability and computer and game aptitude between learners. These challenges remain significant to the educational use of computer games.

SimCity is one the computer games most researched in relation to education (Kirriemuir, 2001). Pahl (1999) believed it was a game that could enhance learning in any curricular area. That broad claim was based on the premise that *SimCity* could be used to teach higher order thinking skills and that all curricular areas could be improved by directly teaching higher order thinking skills.

Dempsey (1996) reviewed published research on educational uses of games since the first wide spread adoption of commercial computer games in the classroom in the early 1980s. The study was largely limited to "instructional games which used some form of technology and were substantive in nature" (Dempsey, 1996). Of 84 articles identified and reviewed, 43 dealt with simulation games, 10 dealt with adventure games, 4 dealt with puzzle games and 26 dealt with "other" games. The "other" category included both games that did not match identified categories and articles that did not identify game genre. That the majority of games were simulations may be an artifact of the longer research tradition on games as military and business training tools (Egenfeldt-Nielsen, 2003). Both traditions favor simulation as the most suitable game genre for their purposes. Dempsey (1996) speculated that simulation games might be favored because they closely align with trends that endorse experiential learning. More than half (45) of the articles did not identify a learning outcome targeted by the games. Roughly one quarter (22) of the reports dealt with games attempting to teach higher order thinking skills like problem solving. Just under one quarter (17) were focused on teaching concrete concepts, rules or material.

Dempsey (1997) surveyed subjects using a cross section of education games and identified key features that subjects regard as essential for a good gaming environment. Three main concerns were: first, the need for clear, concise instructions describing how to play the game. Second, the game should be challenging. Third, the player should have control over many gaming options such as speed, degree of difficulty, timing, sound effects and feedback. Lack of goals, instructions, control and interactivity across all game types were a main source of frustration for players in the study. Many of the games used in this study were typical shareware games lacking in 3D color graphics. The subjects found the screen designs to be boring. They remarked about the lack of color in some of the games and the lower sophistication of some of the screen designs. This finding runs counter to a belief that educational games can cut out frills like color and animation without impacting student engagement (Prensky, 2001). The amount of experience a subject had in playing a particular game did not appear to influence the amount of time spent in game play. There were specific games that subjects felt did not have a place in an educational setting. Most players, male and female, felt that games containing violence had no place in education. Several card games depicted a gambling scenario. Several players felt this was inappropriate, especially for children (Dempsey, 1997).

There may be some confusion here on the issue of what makes a game engaging and potentially reward versus the common use of the word "fun". Many hours of computer games – and indeed non-computer games - can be spent to accomplish the game goal while not in and of themselves being perceived as fun. An external observer might easily assess computer game time as frustrating, annoying or boring to the player and yet still see a players completely committed to continuing the game experience. The term *hard fun* has been used by some researchers to denote this type of gaming experience (Heeter, 2004). What is motivating about games is a drive to overcome a challenge that the player perceives as within their reach (Hogle, 1996).

Carlson (1998) observed that one major goal of educational games is to allow students to play with complex systems to gain an understanding of them. This statement really only applies to those games that fall into the category of simulation. It has been noted that much of the learning tied to simulation games comes from discussing the experience (Frye and Frager, 1996). Several researchers have warned that without allowing time for debriefing and reflection, the greatest potential of educational gaming can be lost (Chiodo and Flaim, 1993; Gee, 2003; Squire, 2004). These researchers advise that guided reflection is necessary to emphasize that the game is being used for educational purposes and not simply for entertainment or a time filling activity. This condition should be readily recognizable as very similar to the situation teachers face when using video media in class. Levine (2002) found that having students play *SimCity 3000* in small groups promoted spontaneous discussion about the concepts and strategies modeled in the game.

In 1990, Csikszentmihalyi published a theory of sustained engagement that he called *flow*. According to Csikszentmihalyi, people enter a flow state when they become completed immersed in an activity and feel at one with it. He identified eight characteristics that are recognizable (and required) when a person is in a *flow* state:

- Feeling the activity can be successfully completed
- The player can concentrate fully on the activity
- The activity has clear goals
- The activity provides fast feedback
- Deep involvement in the activity
- A sense of control over the actions necessary to perform the activity
- Self-awareness disappears during flow
- Altered sense of time

Expanding on the work of Malone and Lepper (Malone, 1980; Malone and Lepper, 1987) on what makes computer games engaging to players, game researchers have adopted *flow* theory to explain the phenomenon of player immersion in computer and video games (Jones, 1998, Steinkuehler, 2004). Jones (1998) argues that flow theory explains the allure of games, and that the experience of flow in the game is sufficient reward for players to game without any other motivation. It may well be pursuit of a flow state that motivates players to try new games and to repeatedly play old games. The ability of games to attract players into a flow state where they spend considerable time engaged in a game is one of the elements most sought after by advocates for the use of games as educational media (Gee, 2003). An educational activity that has some of the elements of a game, but cannot draw students into a flow state, will likely fail to meet the expectations of educational games researchers.

While earlier games research tended to focus on learning specific content in the form of facts and concepts, recent studies have focused more on the notion that students can learn critical thinking and problem-solving skills from games (Jillian, 1999; Ko, 2002; McFarlane & Kirriemuir, 2003). Adventure games have been particularly attractive to researchers in this area. Such games require players to solve puzzles, overcome difficult situations with limited resources and develop strategies to be successful. Since problem-solving and critical thinking are desirable traits to foster in students, games that require those traits to succeed should be powerful learning tools (Gee, 2003). As yet, there are not strong studies showing that games develop these skills, but Ko (1999) has shown that players with strong problem-solving skills perform better in adventure-type games than player with poor problem-solving skills. The assumption usually made is that like working a muscle, playing a game the demands problem-solving, strengthens the ability.

Virtually all research on the uses of games as educational media calls for further research (Egenfeldt-Nielsen, 2003). Acceptance of the idea that games have educational potential has become noticeably more widespread since the dawn of the new millennium. There is a growing body of published reports of uses of games in education, but few of those reports are based on rigorous testing methods (Kirriemuir and McFarlane, 2004). Despite this, the majority of researchers have moved on to issues of how, rather than if, games can be used in education (Gee, 2003, Squire, 2005, Steinkuehler, 2005). At the Games, Learning and Society 2005 conference, none of the 24 sessions questioned the assumption that games were powerful learning tools that should be used in both formal and informal education (Games, Learning and Society, 2005).

Research on the effectiveness of computer games as learning tools is clouded by the ongoing difficulty in concretely determining what constitutes learning (Futurelabs, 2004). There is not common agreement, even in the educational research literature, on what truly constitutes learning. Atherton (2004) discusses the history and current state of the battle to define learning. The inability to reach a consensus is neatly summarized with the remark, “even if psychologists ever agree about what learning is, in practice educationalists won't, because education introduces prescriptive notions about specifying what ought to be learnt” (Atherton, 2004). If psychologists, cognitive scientist and educational theorist cannot agree either in their own fields or across disciplines, how is the researcher studying educational computer games to proceed? Researchers have mainly employed two strategies for dealing with the problem. Some have simply used terms like learning and education without defining them (Nieswand, 1986). This seems to be the most common method of dealing with the issue. Presumably the researchers proceed from an assumption that reasonable people understand what learning and education are, so the terms can be used freely without need to define them. The other main approach is to narrowly target an aspect of what might be considered learning and deal only with that aspect. Malouf (1987) investigated the issue of continuing motivation when comparing games to traditional teaching methods. Pierfy’s (1978) review of the literature was concerned primarily with retention. Both areas could be considered elements or supporting skills for learning.

Whichever approach researchers take, the lack of consensus on what learning and education mean opens their research to charges of failing to define learning. If they do define learning, they are necessarily opening themselves to charges that they are in error. Prensky (2001) suggests that research questions about educational uses of computer games need to very specifically address the issue of who is supposed to be learning what. It is worth noting that schools and universities continue to do their daily work of educating around the world completely uninhibited by the fact that psychologists, cognitive scientists and educational theorist cannot agree on a definition of learning.

Ellington (1981) addressed the challenge leveled against considering games as education media more than two decades ago: “The lack of hard evaluative evidence is used by some workers to disparage the use of gaming and simulation techniques, despite the fact that the use of more traditional teaching methods has no better empirical justification.”

Who plays games?

In an episode of the Emmy-nominated, animated, sitcom, *King of the Hill* (*King of the Hill*, 2002) one of the lead characters inadvertently walks in on a teenage boy playing computer games in a darkened bedroom. The boy looks sickly and pale and reference is made later to his pasty complexion being a result of staying inside playing games rather than getting out in the sunlight and fresh air. The stereotype of computer and video game players as socially awkward teenage boys playing obsessively in darkened, semi-concealed locations persists in popular culture (*King of the Hill*, 2002, Gee, 2003). This stereotype is more fully addressed in Appendix B.

According to a 2004 study by the Entertainment Software Association (ESA), however, the average computer and video game player is 29 and is almost as likely to be a female as a male (ESA, 2004). Indeed, depending on the game platform, the average player is more likely to be female. A Pew study (Jones, 2002) found that 60% of college women reported playing computer games while only 40% of their male peers did. The study also found that equal numbers of males and females report playing console games. Unfortunately, ESA has only released selected results of this study without disclosing raw data or copies of the instrument (Heeter, 2004).

According to a 2002 study, the average American child plays computer or video games for seven hours each week and accesses the Internet from home for 4 hours each week (National Institute on Media and the Family, 2002). A 2004 survey found that half of all Americans - roughly 150 million people - report playing video games, and that a third of the most active gamers are under 18 - about 45 million young Americans (ESA, 2004). The National Institute on Media and the Family (2002) found similar numbers with 92% of children ages 2-17 playing video or computer games. Computer games have become nearly as commonplace as televisions, radio and telephones. Growing numbers of people are trading time in front of the television for time at the computer. That is significant both for the trend itself and the statement that computer time is not just being carved out of outdoor activity time. Proponents of limiting computer time often write as if the time kids spend on computers is time they would otherwise spend outdoors (Stohl, 1999). Interacting with the computer is as common and natural for today’s teenagers as hanging out at the mall was for their parents.

A study by Funk and Buchman (1996) of middle and high school students found that boys spend more time playing computer games than girls do. Their research also found that boys were more likely than girls to identify playing games as their favorite activity. Just as involvement with a specific game platform has an impact on who plays games, so to does genre. Boys tend to favor action games with a heavy emphasis on fast reflexes and good hand-eye coordination while girls prefer problem solving and exploration (Gorriz and Medina, 2000). There is research indicating that females tend to prefer games where the player is not restricted by time and speed of play for success

(Kafai, 1996). Gender preferences should not be taken as absolutes. While many females prefer collaborative, building games, 350 women on 48 teams played the first-person-shooter *Counterstrike* for $30,000 in prizes at the 2005 Electronic Sports World Cup in Paris (ESWC, 2005).

A British study on the gaming habits of elementary and secondary students found that only 4% of students reported disliking playing computer games (UK Children Go Online, 2005). The same study found that 89% of students estimated that they actively played between 1 and 12 computers games each month. In the US, where 239 million computer and video games were sold in 2003, it is very likely that the number of players and number of games are similar (ESA, 2004).

Why consider using computer games in education?

Commercially produced traditional games have been used in education in America since at least the 1960s (Apt, 1968). When personal computers started making their way into schools in late 70's and early 80's many educators started looking for ways to reap the presumed educational benefits of the new machines. Automated versions of traditional classroom activities like drill and practice and quizzes were soon on many classroom computers. Some teachers – largely those with a personal interest in computers outside the classroom- began looking for and using computer games with educational elements in them. Some earlier popular successes included *Oregon Trail* and *SimCity* in the mid-80s. The popularity of computer and video games as entertainment media has exploded since the 1980s.

Many researchers have claimed that the entertainment software industry now generates more money than Hollywood. While the game publishers are doing well, it should be noted that the claim is only true when comparing Hollywood box office dollars to game industry total sales. It does not factor in the enormous revenues from video and overseas sales that make up the bulk of Hollywood's income. Still, the entertainment software industry is very large by just about any standard. According to the Entertainment Software Association, in 2004, roughly 140 million Americans played computer and video games.

One reason to consider games as a format for educational content is that games may encourage players to spend more time with a subject than they would without the game (Lepper and Malone, 1987). A well-designed game can hold a player's interest for hours. The average, commercial game can require fifty hours to master (Gee, 2003). If the game involved educational content that would mean considerable time on task with the expectation that greater understanding and retention of material would result (Trabasso, 1987).

Stealth Learning

There are many who believe the power of games to educate comes through *stealth learning* – the learning that happens without the player being aware they are learning – that happens as players strive to win (or simply explore) games (Falstein, 2002). Renowned games researcher Kurt Squire reports that he learned the geography and partial history of the Caribbean from playing Sid Meyer's *Pirates* (Squire and Jenkins, 2002). *Pirates* was not developed or marketed as an educational game, but the excitement of the game was enough to keep a young Squire playing enough to absorb information that would eventually be helpful in school. It is not unreasonable to suppose that many other players of that blockbuster game also learned the coastline of the Caribbean, which nations settled which regions and never to attack a galleon with a frigate in a head on fight. The last may not have immediate practical application in the 21^{st} century. *Pirates* was not designed as an educational game. The learning that happens while playing primarily enhances the player's ability to be successful in the game. It is almost certainly because there are in-game opportunities to use it and rewards for doing so, that makes *stealth learning* so powerful. In schools, learning tends to be a self-contained activity, while in games; the point of learning is to win the game (Gee, 2003).

Sharing Frameworks

A common difficulty confronting experts is an inability to accurately remember what it was like to have little or no understanding of their field of expertise. Often they have expectations that a concept or principle is simple to grasp universally, because it is simple to understand from their position as experts. This creates a barrier to dealing effectively with novices in the knowledge area. What is a simple matter for an expert is often a complex, confusing or wholly unintelligible jumble to a novice. Games can create a context for new knowledge that can help novice users build an intelligible mental model from a jumble of seemingly disconnected facts.

Common Experience

Dewey (1922) observed that the best teachers build bridges between students' existing knowledge and beliefs and the institutional curriculum. If a student cannot link new information to existing knowledge, the new information is unlikely to be absorbed in a meaningful way. It is a very demanding task to assess the pre-existing knowledge of an entire classroom of students on an individual basis. One way to at least partially fulfill Dewey's requirement is to provide students with common experiences. The prevalence of computer games in popular culture makes it a virtual certainty that a computer game used in school will relate to other games with which students are familiar. Thus games could be a means of building bridges between students' existing experiences and the body of curricular material schools and society require students to learn. They could also be used as automated assessment tools to gauge students' pre-existing knowledge.

Soft Failure

One of the strengths of video games as educational tools is that they allow the opportunity for what has been called *soft failure*. Traditionally when students fail, there is a penalty. Whether it is a poor grade or simply a red mark on homework, the failure is an end in itself. In video games, failing at a task is usually a temporary set back. In a first person shooter, for instance, failure usually means having your avatar killed. In most such games, a new copy of the avatar is spawned relatively quickly. In solo play, the game is reset to before the death, and the player is free to try again. In a multi person game, the avatar may respawn at a set location, and the player is free to get back into the action. In both cases, the failure (death) gives the player both a chance and motivation to figure out ways to improve. The player may decide that a different approach is needed or may presume that they were simply unlucky. Repeating the attempt will help the player decide between the two cases. Eventually, the player will either discover a successful approach or find out that it was just bad luck. Either way, the experienced failure encourages the player to experiment and learn from the situation. That sort of repeated effort to solve a problem is one of the keys to success. The old adage goes, “if at first you don’t succeed, try, try again.” There is no respected adage that says, “if at first you don’t succeed, accept the poor grade and move on.”

There is a temptation to say *soft failure* is low-stakes failure, but that temptation should be resisted. *Soft failure* means a chance to try and fail without fear of long-term consequences. Low-stakes failure implies that there is a long-term penalty even though that penalty is minor. With true *soft failure*, any penalty that is imposed should be wiped out by eventual success. In the academic world, it is rare to find a teacher who takes a “keep trying until you get it right” approach to testing or homework. Under that system, no grade ought to be recorded until the student has had as many attempts as they are willing to make to get a result they are satisfied with. It is far more common to give a student a permanent grade while encouraging them, contradictorily, to learn from their mistakes. The grade removes the incentive to revisit the material. Games, on the other hand, can be powerful education tools because they encourage returning to the material over and over again. The engagement is the intrinsic motivation to return.

Quick Feedback

Games and simulations provide rapid feedback. One issue that is discussed in relation to computer-based teaching is the impossibility of having a program that could intelligently respond to all of the questions and difficulties a student would have. The argument goes that the system would have to be as sophisticated as a human being in order to do the job properly. Games, like other electronic educational media, get around the issue by limiting the options a player can deal with. The game does not purport to address any area outside the domain of the game. So the game is only giving feedback in its area of expertise (i.e., itself).

Games provide feedback quickly. A player attempts an action and knows very soon whether it was successful in most games. In terms of learning, a game could tell whether a math problem was answered correctly and physics formula was laid out accurately. If the input was correct, the user knows instantly. If not, the user keeps working at it. The failures are soft. There is not penalty for getting it wrong other than needing to make additional attempts. Only ultimate success is important.

There is a very good reason why a teacher cannot always provide instant feedback and the opportunity to make repeated attempts on an exercise. The time demands on the teacher would be prohibitive. Every student would need to be able to interact with the teacher individually on-demand. The teacher would have to continue checking tests and homework answers – and responding to them – until every student was satisfied with their outcome. Time management is a serious issue for teachers even under the traditional "one try and a grade" system. It would be impossible in a "repeated attempts and instant feedback" system.

Problems with computer games in education

Many discussions about computer and video games in popular culture can quickly turn to perceived problems. Often, but not always, the individuals seeing the problems with games are not themselves games players. Both socially and academically, discussion of games is likely to hit upon concerns. This section of the paper deals with some of the more common concerns both about games in general and in specific application to education.

Games are not serious enough

A British study using commercial games in classrooms found that one major issue teachers participating in the study encountered was the belief that they were not doing serious teaching (BECTA, 2001). Administrators, colleagues, parents and even students may doubt the academic value of using games in the classroom. Massanari (1998) reports concerns expressed by teachers that using computers to play educational games might make it harder to get students to engage in more conventional learning tasks on the computer. The worry appears to be that students will come to expect all computer learning to be fun and will reject educational uses of computer that do not meet that standard. On the other hand, Mackerth (1998) argues that playing games on the computer helps to foster confidence with the technology. Cassell and Jenkins (1998) believe that early engagement with computers through games can help students develop strong computer literacy and prepare them for futures in technical careers.

Constraints in the Classroom

There are logistical concerns about using computer games in classrooms. Most games are designed to be played by a single person sitting at a single computer. Even multiplayer games are usually based on the assumption that each player has their own computer. Those expectations are not always realistic in a school environment, where the national ratio of students to computers is still nearly 5-1 (National Center for Educational Statistics, 2004). Teachers can have students work as teams to play games as one way around this issue (Pahl, 1991). Such group play also promotes reflection and deeper learning during the activity. Some computer companies design games with educational application with team play specifically in mind (Muzzy Lane, 2005).

Time is another significant factor. Most commercial games are not designed to be played in the 45-50 minute increments that are common to school class periods. Even if a teacher selects games tailored to that time span, getting a room full of students all up and running successfully can be difficult without technical support. Many teachers who might otherwise consider using games in their classrooms are likely to reject the idea due to time constraints. This consideration prompts some to dismiss games as a suitable tool for formal education and relegate games to an informal or support role. Lepper and Malone (1987) addressed problems in using computer games educational purposes. They felt limited school hours would not be best used teaching students how to play educational computer games. They supported the use of computer games in the home to enhance formal education so that students' free time and not school time would be spent on the computer material that was not directly relevant to the curriculum.

Addiction and Antisocial Behavior (Myth 1)

Stohl (1999) expressed the concern of many parents and teachers when he published the conviction that computer games displaced other, more worthwhile activities among children and students. He included in his charges that computer games are addictive. Creasy (1986) found that in the initial intense interest of new games players displaced other activities temporarily but time committed to games decreased quickly. Durkin (1995) found that the stereotypical obsession with playing games was episodic rather than constant as typically claimed (Stohl, 1999). As is often the case with stereotypes, it is likely the model of gamers completely obsessed with video games to exclusion of all else including sunlight, exercise and social interaction is a caricature based on selective consideration of evidence. While there are many gamers who play obsessively periodically, there are few verified reports to match the stereotype. Microsoft released Halo 2 on November 9, 2004 with record-breaking sales of more than two million copies the first day (GamesSpot, 2004). By November 11, reports of players beating the games began to appear on the Internet. Since the game can be expected to take at least 20 hours to play all the way through, some players were likely living up to their promises to skip work or school to master the game. Playing a game for more than twenty hours in two days is probably a bit obsessive; especially if the player is shirking standing commitments to do so. But it is reasonable to believe that the Halo 2 fanatics who did so went back to work or school after they beat the game. Otherwise there would have been a rash of news stories about Halo 2 causing serious problems for players. The reality is that most of even the most obsessive players only play obsessively when they have a new game that hooks their interest. It took three and half years to develop Halo 2. A chain of blockbuster releases did not follow it week after week after week. Most computer and video games lose their compelling sense of excitement over time. The more obsessed and committed the player, the sooner they are likely to beat the game. Even if a player wanted to stay in an obsessive state about games, there are simply not enough quality game releases to maintain it.

Violence (Myth 2)

The majority of reports linking games to violence come from two major sources: The National Institute on Media and the Family (NIMF) and the self-identified violence consultant David Grossman. NIMF is a media watchdog group founded and run by David Walsh, his students and family (National Institute on Media and the Family Website, 2005). Grossman is a former US Army colonel with a background in psychology (Killology Research Group website, 2005). In the face of more than a decade of declining violence according to FBI statistics, Walsh (1998) and Grossman (2001) publicly site video games as a significant cause of increasing violence in America.

The research on computer games leading to increased aggression is based on asking study participants if they feel more aggressive after playing video games. It is not based on actual cases of demonstrated aggression. While this is a typical method of research, it does not demonstrate a causal link between computer games and aggression. At worst it supports the claim that some computer games players believe that they feel more aggressive after playing violent video games. To date, there is no widely accepted study that shows that playing violent computer games, watching violent television shows, or listening to violent music leads to violent behavior. Belief in a linkage persists, but so far, the linkage is no more substantiated than any other urban legend. Like Big Foot and the notion that NASA faked the Apollo Moon landings, the myth that video games lead to violence remains present but unfounded.

Games not edutainment

Many efforts to make educational games result in products that fall short of the creators' expectations. Most kids will not voluntarily touch a game if it is labeled 'educational'. It's like eating food that is supposed to be good for you. The labeling hints that what is inside the package must be short on other merits if the manufacturer has to add "for you" after claiming the product is "good". Imagine the difference in reaction from a class told, "Now we are going to play a game" from one told "now we are going to play an educational game". All but the most wide-eyed optimist should be able to imagine a difference. In the 1980's the games designed specifically for education were dubbed *edutainment*. As noted in the history section, *edutainment* gained a poor reputation because the majority of *edutainment* titles ranged from boring to not horrible (Games Museum, 1999). Any serious use of games as educational media today needs to avoid the stigma of *edutainment*. That means both avoiding the label and not trying to pass off bad games as entertaining and educational.

NASA and Games

The Report of the President's Commission on Implementation of United States Space Exploration Policy (2004) recommends that NASA find ways to leverage the power and popularity of computer and video games to inspire and educate the next generation of explorers. NASA has no direct control over how games will be used in education, but still has to make choices about whether to develop games to be used in formal or informal educational settings. The broad language of the recommendation leaves open the possibility of using games in classroom, in informal education venues and for home use. In response to the report and as part of the NASA strategic road mapping efforts in 2004, several individuals and teams submitted responses to the recommendation that NASA use popular media like computer and video games to inspire and educate. Below are summaries of the public responses to NASA's request for information (RFI) on educational uses of computer and video games. The full text of these submissions can be found in Appendix D.

Responses to RFI

William Davis, Executive Producer, America's Army Future Applications
Todd Borghesani, Director of Special Projects, NASA-Sponsored Classroom of the Future.

Davis and Borghesani recommend that NASA "ride the wave" of 3D gaming popularity and use a commercially available 3D gaming engine to develop an online science and exploration gaming environment following the model of *America's Army*. They specifically recommend the *America's Army* technology as the backbone of a NASA game presumably to leverage the Army's investment in gaming technology. They recommend a series of modules that meet the specific needs of NASA strategic road maps. The common theme is simulated environments and equipment interfaces based on NASA data presented through the medium of a 3D game. They recommend developing an MMOG where users can become familiar with real NASA data, work and play collaboratively, learn about existing NASA technologies, attempt to design and test virtual systems and run virtual science experiments. Davis and Borghesani believe that a well established MMOG could not only be a learning environment tailored to meet national standards, but could also become a reliable conduit for disseminating new NASA data to a large, well-established user-base. The pair specifically cites lunar and Martian exploration, International Space Station experiments and robot and Space Shuttle system controls as likely material to simulate in a NASA game. This recommendation is more accurately described as calling for a complex, online, simulation environment based on NASA content based on gaming technology, as there is no specific discussion of game play.

Kurt Squire, University of Wisconsin-Madison, Educational Communications and Technology

Squire shares the benefit of his research and experience with educational games to inform NASA of some of the existing successes with games and the amazing potential games researchers see in gaming technology. Squire cites Bell Labs science film series known as *Operation Frontal Lobe* as an example of tapping into a popular medium (television) to enhance science understanding and literacy in the American public. *Operation Frontal Lobe* was developed in response to Sputnik and recruited established Hollywood talent to create quality science programming that was both educational and entertaining. Squire recommends that NASA be part of creating a new *Operation Frontal Lobe* to bring together scientists, learning scientists and game developers to create deeply educational and fun science and exploration games. He recommends a MMOG where players form self-organized teams to achieve in-game goals that improve their game avatars, enhance player understanding of science and engineering concepts and promote collaboration between experts and novices. Squire points out that US Army, the American Home Builders' Association, Christian evangelists and even radical political groups in Spain have already begun using MMOGs to "push their agendas". He calls scientists and educators with a vested interest in public education to "take up games as a medium".

David Williamson Shaffer and Gina Navoa Svarovsky, University of Wisconsin-Madison, Academic ADL Co-Laboratory

Shaffer and Svarovsky recommend that NASA develop what they call an *epistemic game* based on the practices and education of NASA professionals. *Epistemic games* are computer games based on the practices, values and knowledge of a specific community. In this case, Shaffer and Svarovsky are proposing that an ethnographic study of NASA professionals would identify common cultural elements that could be used as a solid foundation for a game to help inspire young people to go into science, technology, engineering and mathematics education. The advantage of such a game is that it channels players into doing the simulated work of real scientists and engineers to begin becoming part of that community of practice. Shaffer and Svarovsky argue that experiencing simulated tasks will be significantly more meaningful to players than the traditional model of "confronting words and symbols separated from the things those words and symbols are about in the first place." The recommendation focuses heavily on the material a game would be based on rather than the structure of a game itself. Other than recommending that such a game be available online to broaden distribution, Shaffer and Svarovsky do not recommend a structure.

Mechanisms for Game Development

There are three primary methods NASA could use to support the development of a game or games:

- Call for proposals to develop a NASA game or games
- Develop a NASA game or games internally
- Author a Space Act Agreement for third party development

Development of a game comparable to commercial games is an expensive proposition. The average development cost of a high-end game is about $5-7 million (Loftus, 2005). The US Army has put $2.5 million a year into the development of the popular MMOG *America's Army* since the project's inception in 2000 (Peck, 2004). With those funds the Army was able to establish several teams of contractors to develop a very successful MMOG for the PC. In the three years since the 2002 debut of *America's Army*, more than five million users have registered to download and play the free game. In 2004, Colonel Wardinski, the manager of the project, announced that the game development company UBISoft has licensed *America's Army* to develop a console version (Peck, 2004). Colonel Wardinski reports that the advance payment and 5% royalties will be used to help offset future game development. NASA could fund a similar effort to develop a large-scale game project.

NASA could consider developing a game or games using existing NASA resources. Facilities like the Scientific Visualization Studio at Goddard Space Flight Center and the Ames Research Center and Johnson Space Center teams that developed *SimStation* have technical expertise closely related to skills used in game design. It might be possible to find sufficient internal resources to develop an education game or games.

A NASA game could be developed in partnership with a game design company through a Space Act Agreement or some other vehicle. In such an arrangement, NASA could supply technical and scientific expertise while the game design company supplied the skills and experience in game development. This is very much like the deal the US Army has struck with UBISoft mentioned previously.

The vehicles for funding development are “game neutral”: they do not in anyway dictate what sort of games could be developed. Several approaches could be taken. One major choice is between developing a game from scratch and supporting the development of a major modification to an existing game. There are a number of space-based games on the commercial market. NASA could develop supplemental materials to make the games educationally useful. Such supplements could range from lesson plans based on experience with the game to the development of a modified version of the game. In the gaming industry, modifications (know by the shorthand *mods*) are common. Most PC game companies encourage the development of freely distributed mods of their games and often include editing tools on the game disk. Mods help keep players interested in games longer and are a cost-free way for a company to extend the shelf-life of a game.

NASA Commitment

Since the Third Wave of Educational Games began, the development of successful educational games, like virtually all other computer games, has been the domain of professional game designers. NASA has supported the development of dozens of browser games, educational tools with game elements in them and several modest stand-alone games. So far NASA’s efforts have been spontaneous and uncoordinated. If NASA is going to follow the spirit of the *Report of the President’s Commission on Implementation of United States Space Exploration Policy* (2004) concerning games, a well planned, coordinated effort will be necessary. The decision about what kind of games to develop will have a substantial impact on budgetary requirements. The choices run from MMOG on the scale of *America’s Army* to browser games. The investment required is substantially different. An MMOG could approach $3 million a year for three to five years. Most of the recent literature on the educational uses of games presumes that higher-end games either of a MMOG, networked or stand-alone type. If NASA efforts to tap the power and popularity of games as educational tools are going to be successful, commitment to a large scale game project will be required.

Human spaceflight is NASA's most dangerous endeavor. NASA has a long history of using simulations for astronaut training (NASA, 2003). Their training simulations are used to provide low-risk opportunities astronauts to learn. The astronauts have to work within the rules and restrictions of the simulations, because those restrictions mirror the real systems that are being simulated. The objective of training simulations, either on computer or in *mock-up* systems is to allow the astronauts to obtain a level of proficiency indicated by reaching a pre-set level of success. In other words, astronaut training simulations are low-stakes (low-risk) contests (against the challenge of the simulation) with rules (restrictions and limitations) and the goal of "winning" the contest (completing the simulation): the very definition of a game. Clearly NASA recognizes the power of games as educational tools.

Appendix A

Lexicon

Applet: A java application, online

Application games: PC games, stand-alone not requiring a browser or Internet

Augmented reality: Immersion in a gaming world through use of computer simulation

Avatar: The character that represents the player in a game

Browser games: A game played using a web browser

Client server game: An online game, not necessarily multiplayer, played from the browser

Computer games: Games that require the use of a computer

Console: A dedicated computer system designed for playing games that outputs to a television

Cooperative game play: A multiplayer game in which all the human players play with, instead of against, each other

Drill and practice: A learning technique where the student learns by repetition

First person shooter: A type of game where the player has the first person perspective

Game: A low-stakes contest with rules and the goal of "winning" the contest

Game platform: The hardware system that supports a game

Handheld games: A handheld computer system designed to play games

Hot seating: A multiplayer game where the players share only one computer, turn based

Isometric games: A game with a top down perspective, but on an angle giving a 3 dimensional illusion

LAN party: Game play where players come together and network computers for the express purpose of playing multiplayer games

MMOG: Massively multiplayer online game, large online communities of players interacting during game play (Also called MMORPG for the role-playing variety of MMOG)

Multiplayer game: A game in which there are several interacting human players

PC game: A game that can only be played on a personal computer (usually not used in reference to browser games)

Peer-to-peer game: A limited multiplayer game where the players connect directly to each other online to play

Server game: A multiplayer game where the players connect to a server to play online

Simulation: A model that is operational and based on something real

Soft failure: A consequence free penalty encouraging the student to repeat and discover

Solo game: A game in which there is only one human player

Spawned: The recreation of an avatar during game play

Stealth learning: The learning that occurs while doing a non-learning activity

Text-based game: A game based on text and descriptive pictures, no animations or active movement

Top down game: A game with a top down, 2D, perspective

Traditional game: A non-computer game

Video game: A game played on dedicated computer console that displays the play action through a television

3D game: A game rendered in three dimensions, capable of being viewed from any perspective

Appendix B

Stereotype of Gamers

It may seem unnecessary to include the laughable caricature of gamers in a serious paper on games. However, stereotypes tend to be persistent and stubbornly resistant to change even when logic and evidence ought to negate them. A reader burdened with such stereotypes about games and gamers will have difficulty considering much of the work on games as educational tools without confronting their existing mental models on the area. Teachers who have tried to use computer games in schools have reported that parents, administrators and even other teachers and students have perceived the use of such media as inherently frivolous (BECTA, 2001). It would strengthen the character and quality of the debate over computer games as educational media if the proponents of every side were more aware of their pre-existing attitudes and beliefs. Research has shown that established beliefs create a strong filtering system that tends to bias the assimilation of new information (Lord, Ross and Lepper, 1978). Simply admonishing individuals to be aware of their existing beliefs and on guard against assimilation bias when reviewing evidence has little effect (Ross and Nesbitt, 1984). Suspending disbelief by consciously pretending to believe new evidence while encountering, however, has shown significant success as a tool facilitating less biased assessment of evidence (Laughlin, 2001).

There may have been some good reasons for developing the stereotype of computer gamers. Creating stereotypes is a normal function of the human brain in its continuous effort to organize its understanding of the world. Stereotypes are generalized sets of rules to help categorize and make predictions about particular things. All stereotypes are caricatures by nature, as they are based on gross generalizations about imperfectly understood classes of things based on limited observation and input. It is important to keep in mind that stereotypes are always about things that are not intimately familiar or well understood. They are a shortcut to save time and brain power. Like all pre-existing beliefs, they tend to be stubbornly resistant to change once established.

Consider the development of the first persistent computer game, *Spacewar*. In 1961, members of the Massachusetts Institute of Technology's (MIT) Tech Model Railroad Club (TMRC) encouraged one of their own to develop an interactive computer game. The TMRC was made up entirely of male students. Because computers were a rare and costly resource at the time, the TMRC had to make use of "borrowed" computer time at night and on weekends when legitimate users were not around. The cathode ray tube display they used could be more easily viewed in a darkened environment than in a bright one. The TMRC had their own jargon that they used when discussing their projects and interests. Both the topics and the language would have been hard to understand and of little interest to most outsiders. The first complete version took Steve Russell six months and 200 hours of otherwise free time to complete. Had he not had dedication and commitment to the project, it would likely never have been completed (Kent, 2001).

In that story are all of the elements of the stereotype of computer gamers as well as programmers and most other classes of dedicated computer aficionado. It is not improbable that many readers anticipated a word like *geek* as the last word of the previous sentence. Even intelligent, reasonable, open-minded people are subject to the pervasive power of stereotypes. Each of the elements of the computer geek stereotype could be seen in a good light in the *Spacewar* story: each is not inherently negative. The actors speak common jargon like any other specialized field of interest. That language is inaccessible to outsiders by its very nature. What in the stereotype is called obsession can be clearly seen as commitment. The secretive, darkened environment is necessary because of the tenuous rights of the TMRC members to use the valuable computer resources and the limits of the screen technology. Most of these elements are no longer factors in the modern world of computer and video games.

Computers are no longer a rare and exclusive resource. The majority of households have computers and video game consoles so the technology is not inherently limited to dedicated enthusiasts willing to bend rules to get access (ESA, 2004). While some studies still find a difference in the level of interest in computers between males and females, the most recent studies report a narrowing gap (Heeter, 2004). The jargon of computers and computer games persists, but much of it has filtered into mainstream usages and the size of the domain affinity group has ballooned to the point where it is no longer an exclusive club. Social interactions around and about computers and computer games have become mainstream rather than fringe. Indeed, with 92% of 2-17 year-olds playing computer games, the hobby can hardly be considered clandestine (National Institute on Media and the Family, 2002). Advances in computer monitor technology mean that most screens are as readable in direct light as they are in a darkened room. Portable technology for both computers and consoles means that games are quite literally moving out of basements in into the outdoors. Since it still takes time to beat the biggest, most challenging and rewarding games, however, the element of obsession still has a place in the description of many computer and video gamers.

Appendix C

Lost Games

There must be a disclaimer about the ephemera of games when discussing the history of computer games in education. Any historian knows that the records we reconstruct of the past are incomplete. It is beyond the scope of our ability to capture or recreate other times and places in their entirety. Our history of ancient Egypt, for instance, is based largely on the contents of tombs, fragments of writing, remnants of stone structures and other scraps that disproportionately fall into the categories of either treasure or trash. What we have is significantly less than 1% of all of the human-generated material from the Nile Valley 5000 years ago. Historians have created our modern model of what Egypt was like based on that fraction of a percent. There must be significant gaps in our knowledge of the world of ancient Egyptians, but all we can do is keep searching for more clues to improve our model.

When we look at the more recent history we tend to have more of the original material on which to build our model. But we still do not have everything. When dealing with the history of computer games in education, we are plagued with a lack of documentation. Most people involved were busy either making the educational games or using the educational games: few were sitting down and documenting the use. This point is not meant to be facetious. Even though the time involved is barely three decades, many educational games may have been lost. MobyGames, an organization dedicated to cataloging computer, video and arcade games, has built a database of games that reached 20,000 titles in March 2005 (MobyGames, 2005). That is the most complete list of computer games in the world. The database, however, only includes the games that have been entered into the database by contributors. Any game title that has not been contributed, effectively never existed according to MobyGames. Since the database has grown from nothing to 20,000 entries since it was started in 1999, it is safe to assume that some games have been missed. The likelihood is that the more obscure the game, the less likely it is to have been added to the database. The MobyGames database lists 442 games that contributors describe as educational. There is no guarantee that list is complete even for the types of computer games the systems records, and it only records commercially released games. It does not include non-commercial games or games designed and distributed exclusively over the Internet. Such games tend to leave a less permanent impression on the world. They are the sorts of educational games that will be most likely to have disappeared by the time the history of computer games in education is written.

The Beasty Game is an example of educational computer ephemera. According to traces found online, *The Beasty Game* claimed to be the oldest computer game. The player was supposed to think of an animal and then answers a series of yes or no questions posed by the computer. Based on the answers the program would "guess" the type of animal. The success rate was apparently impressive. *The Beasty Game* was a computerized version of the word game "twenty questions." By restricting the topic to animals, the program was able to do a better than expected job at "guessing" the correct animal. *The Beasty Game* claimed to have been a tool for teaching reasoning. The game was originally freely distributed on floppy disk, but converted to a Web-based format at some point. Today, a Google search results in nearly 100 hits. Unfortunately for anyone wanting to find the game, every single link leads to a “page not found” error message. *The Beasty Game* is gone.

Appendix D:
Response to Request for Information

Game Technology Applied to Education in NASA Strategic Roadmap Focus Areas

William H. Davis, US Army ARDEC wdavis@pica.army.mil 973 724 7689
Executive Producer, America's Army Future Applications
Todd Borghesani
NASA-Sponsored Classroom of the Future todd@cet.edu 304 215 0328
Director of Special Projects

The partnership of NASA's Classroom of the Future and America's Army Game Project suggests and proposes the use of 3D game technology as a means to link many of NASA's Strategic Roadmap areas to Education and Outreach.

3D and other game technologies represent the fastest-growing and most engaging, efficient and cost-effective way to reach out and engage not only students but a broad cross-section of America. This business and technology model has been proven with the creation, deployment, and continuing success of one of the world's most popular 3D online games, America's Army. COTF and AA want to use this approach to reinvigorate interest and support in NASA, the US Space Program and science in general.

With today's computers, internet and 3D technology, game players in different parts of the world interact and communicate with each other in realistic 3D virtual worlds. AA players by the thousands link up every day to perform cooperative missions; and while the Army application includes by nature some degree of violence, strict adherence to rules of conduct, laws of land warfare and codes of conduct are requisite to participation, and are enforced. Thus the underlying values of an organization…be it the Army or NASA…can be architected into the fun and engaging virtual experience.

The Army is taking networked gameplay a giant leap further by applying the underlying technologies toward serious applications…training, mission rehearsal, concept exploration, robotics and more. By extension, games built to educate and engage students and the public about space exploration can be modified and applied to address similarly serious NASA efforts in the very same or analogous areas and disciplines.

A good example is in the representation of Mars surface operations. Using a 3D game engine as a development platform, we can develop, with geographic specificity, the terrain of any landing site, the spacecraft and other elements…spacesuits, robots, manned mobility platform, communication, interaction with the environment. In space applications, the adversary is the environment…in the gameplay one will experience serious consequences if a helmet is not properly sealed during an EVA. Players will be able to experience the first steps to the surface, raising the flag, taking the first samples, seeing their shipmates emerge from the landing craft. They will be able to communicate over the internet (using IP applications and headsets), and work together, even with people sitting in other countries, in building the first base on Mars, exploring the site and conducting science operations. (The science can be linked to other game types or more standard curricula.) The same 3D technologies can be extended to researchers, creating a virtual multiplanetary testbed to try out new capabilities. If properly set up, games for outreach can engage students and the general public in such a way that large numbers of people could meaningfully contribute to the development of new ideas for space exploration. The general nature of the development tools means that we can be putting people in virtual representations of any place…the ISS, Moon, Europa...or in a research facility at Kennedy Space Center or in Baikonur, learning about space-related professions. The implications for international cooperation between researchers and citizens are obvious.

The advantage of using a commercial game engine as a development platform is manifold. Young people…and in fact a growing segment of broader age groups…are familiar and comfortable with 3D multirole online gameplay and its associated paradigms. The required household penetration of broadband internet connections has happened and is only increasing. The 3D game engines advance at a pace faster than the development of the 3D PC hardware, driven by the insatiable appetites of people worldwide for ever more realistic entertainments, with no end in sight. Thus the public is paying the game entertainment industry to continually improve the underlying software; this is a wave to ride, and not attempt to duplicate. The resulting ability to simulate real world attributes…lighting, gravity, interaction with objects in the environment and other people, the entire visual and auditory experience of *anywhere*…allows engaging gameplay in realistic worlds and spaces, and this same set of attributes makes the technology attractive for immersing trainees, researchers and astronauts in these same (or extended) environments for a wide variety of serious applications.

A further extension of serious application occurs when we involve hardware interfaces. With America's Army we have given robotic operators training capability by replicating the hardware interface, while they operate a virtual robot with controls identical to what they have in the field. By extension, the 3D game visuals and sounds can provide the stimulus to people training in manned simulators and spacesuit mockups. Thus a single technology type (the commercial 3D game engine) can be a common backbone to education and outreach, and research, training, concept exploration and mission rehearsal.

Specific to Roadmap (1): *Robotic and human lunar expeditions.*
The capabilities described above regarding representing Mars operations extend to Lunar operations. The game engine performs real time physics; in conjunction with animations apropos to movement speeds, a realistic representation of lunar surface human and vehicular mobility is possible. A wide range of human and robotic Lunar activities is amenable to representation in a shared virtual world, for instance, first manned return, Earth-based operation of robotic explorers, Lunar exploration, resource extraction, and base planning and construction.

Specific to Roadmap (2): Sustained, long-term robotic and human exploration of Mars.
A description of a game-based educational learning module based on Mars operations appears above. It is the intention of this partnership to build a demonstration in early 2005; the demo would include some fundamentals such as spacecraft, spacesuits and surface mobility with some gameplay objectives that might include collection of samples, deployment of experiments and surface exploration. Such a demo would feature realistic

technology and environmental representations and attempt to convey the experience of Mars to a player. The demo would also build content that could carry forward into a more extensive fully developed game.

Specific to Roadmap (3): Sustained program of solar system exploration. Robotic applications have been built for training using America's Army. Game-based control of virtual robots lends itself to educational possibilities for all age groups depending on the sophistication of the robotic model and its ability to interact with its environment and with associated learning applications. An example is a virtual Mars rover; at it simplest, very young children can drive it around Martian terrain. In a more sophisticated form, an advanced student could extract virtual spectroscopy with an instrument as a gateway to a spectroscopy leaning module. In the case of manned exploration, the richness of human interaction during operations on the surface lends itself well to mapping into a 3D game application. These types of operations can be extended to any body in the solar system. If the body is not well characterized, an informed speculative representation is apropos for learning applications. Thus game technology can support the educational component associated with exploration of all the bodies of the solar system.

Specific to Roadmap (4): Advanced telescope searches for Earth-like planets and habitable environment. In the search for Earth-like planets or environmental niches for humanity, little data is yet available. In the context of learning applications, however, some creative speculation could be applied to the creation of engaging, plausible planetary and other environments in 3D game applications for the purpose of engaging young minds in the potential for extrasolar homes for humanity to ultimately explore and settle. Thus players would engage in the exploration and even in the physics-based construction of extrasolar worlds, an activity that could evolve toward more realism as data regarding these planets develops over the next decades with the advent of the requisite detection and analysis capabilities in the next generation of planet-detecting telescopes.

Specific to Roadmap (5): Exploration transportation systems. Learning objectives related to the development of exploration transportation systems would associate with systems architecture wherein students would learn to develop and architect transportation systems to include engineering and economics. Learning modules might present building block approaches or more open-ended system design exercises, with levels of detail that could potentially include detailed functionalities specific to craft designed for different purposes such as LEO, lunar or asteroid exploration, or other destinations. Design exercises would culminate in realistically operating virtual spacecraft designed in some manner and degree by students and operated in accordance with their mission. This approach lends itself to an open source/open architecture approach in which student virtual design teams would collaborate toward objectives. There is high potential for meaningful contribution of students to real design exercises.

Specific to Roadmap (6) Complete assembly of the International Space Station and focus utilization. This is an area of game technology based learning that has shown strong hints, via various web visuals, of what might be possible. Certainly we have shockwave web apps that can show assembly sequences, and this ground has experienced lots of traffic. Nonetheless the ISS is still a growing facility and represents the focus of international manned spaceflight. As such there are many possibilities to use 3D game technology in an educational role, and the ability for players to experience each other's physical presence visually, and through sound and text communication, makes it a natural for international student cooperation, exactly analogous to the international teaming that takes place with America's Army (1/3 of AA players are overseas). An entire gamut of varied science research takes place on the ISS, some of which, for instance animal experiments, would play well with broad student segments. An example would be microgravity experiments with mice to determine behavioral or physiological changes. Past experiments have known results that could become a baseline for virtual "ISS pets" (expanding on the GigaPet paradigm in part), in which students will have science objectives yet must care for the virtual animals and adhere to feeding and experiment protocols to realize a successful outcome. In a broader sense the entire interior and exterior of the ISS can be represented as a microgravity game/simulation in which virtual international teams of students perform realistic analogs of station activities including experiments, operations, general living and EVA, as well as welcoming visitors and changing crews as part of a long-term persistent 3D simulation.

Specific to Roadmap (11/12): Educate students and public, and expand national technical skills and capabilities. Engaging 3D games that illuminate NASA activities across their spectrum are now possible. Placing students on terrains that represent any of the bodies of the solar system from Mercury to the Kuiper Belt objects, including remote and exotic locations on the Earth, is an achievable goal. Distribution of the games is very low cost, accomplished via download and CD. Learning activities can span broad audiences, from the simple manipulation of a Mars rover by a 4 year old to shared world planetary operations that can extend over weeks or months, i.e. a persistent simulation with real research goals. It's possible to fully represent the ISS and its operations, including virtual EVAs, as well as the architecting and engineering of space exploration system. The 3D technology would be coupled, where apropos, to National learning standards, and would also interface with other game and web technologies that would augment the public relations and learning experiences.

NASA and *epistemic games*: Using NASA-based video games to inspire, motivate, engage, and educate the STEM professionals of tomorrow

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The low percentage of students who pursue STEM fields suggests that many young people feel disconnected from and disinterested in traditional STEM education, where learning often revolves around memorizing unconnected facts or manipulating abstract equations.

Our work focuses on making STEM subjects more engaging and more meaningful to students by creating and studying *epistemic games* (Shaffer, in press). These informal science education environments are based on the theory of *pedagogical praxis* (Shaffer, 2004b), which suggests that students can develop interest in STEM fields and understanding of STEM concepts by using computational tools to engage in authentic professional practices.

Video games and other computer simulations are important for learning, we argue, because they let people participate in new worlds. In game worlds, learning no longer means confronting words and symbols separated from the things those words and symbols are about in the first place. The inverse square law of gravity is no longer something understood solely through an equation; students can gain virtual experience walking on worlds with smaller mass than the Earth, or plan manned space flights that require understanding the changing effects of gravitational forces in different parts of the solar system. In virtual worlds, learners experience the concrete realities that words and symbols describe. Through such experiences, across multiple contexts, learners can understand complex STEM concepts without losing the connection between abstract ideas and the real problems they can be used to solve. In other words, the virtual worlds of games are powerful because they make it possible to develop situated understanding.

Our work focuses in particular on how virtual worlds modeled on authentic professional activities are especially powerful contexts for developing situated understanding of STEM domains. We have looked at how students can learn about physics by working as engineers (Svarovsky & Shaffer, 2004), technology by working as science reporters (Shaffer, 2004b), ecology by designing cities as urban planners (Beckett & Shaffer, 2004), mathematics by working as graphic designers (Shaffer, 1997), and biology by working as professional mediators (Shaffer, 2004c). In what follows, we briefly describe the theories behind this work, the process of developing these learning environments, and the potential utility of these ideas to NASA's Strategic Roadmap.

A century ago, John Dewey (1915) argued that meaningful learning results from meaningful activity. We learn by doing—not just by doing any random thing, but doing something as part of a larger community of people who share common goals and ways of achieving those goals. We learn by becoming part of a community of practice (Lave & Wenger, 1991).

Much of the work on communities of practice over the past decade has focused on the connection between what people do (*practice*) and how they think of themselves (*identity*). Pedagogical praxis (Shaffer, 2004b) extends the idea of communities of practice by recognizing that participation in a community of practice also involves developing that community's core *values* and *knowledge*—and that practice, identity, values, and knowledge are organized by and around a way of thinking into an *epistemic frame* (Shaffer, 2004a). Aerospace engineers, for example, act like aerospace engineers, identify themselves as aerospace engineers, are interested in aeronautics and space science, and know about aerospace engineering. These skills, affiliations, habits, and understandings are made possible by looking at the world in a particular way—by thinking like an aerospace engineer.

Building a learning environment where learners develop a new way of thinking is hard work. But the good news is that in many cases existing communities of practice have already done a lot of that work for us. Doctors know how to create more doctors, and engineers know how to create more engineers. Thus we develop epistemic games based on the ways in which STEM professionals develop their epistemic frames, and suggest that such games may provide an alternative to traditional school-based STEM education.

To build these games requires understanding how practitioners develop their ways of thinking and acting. We start by conducting a detailed ethnographic study of how the epistemic frame of a community of practice is developed by new members. We use the results of that study to design a computational tool and immersive activities that let students participate in an authentic simulation of the professional practice. Once the epistemic game is developed, we pilot test, revise, and then finally implement the game at full scale in an informal science education setting. Our ongoing work shows that students who participate in the epistemic games we create develop STEM understanding and interest in STEM subjects.

Focus Point 11 on the Strategic Roadmap calls for "NASA missions and other activities to inspire and motivate the nation's students and teachers, to engage and educate the public, and to advance the scientific and technological capabilities of the nation."

We suggest that a particularly fruitful and innovative way to address this goal would be to create an epistemic game based on the training and practices of NASA professionals. A video game and associated curriculum in which students developed the ways of thinking of flight engineers and astronaut scientists would help develop STEM understanding and interest in STEM subjects, and potentially motivate students to pursue careers with NASA. Lastly, providing educators and the general public with online access to the epistemic game would significantly broaden the impact of this work.

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“Serious Games” as Mechanisms for Engaging the Public Sector in Science

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Video games have emerged as an important artform of and for the 21st century. Games allow people to explore ideas, relive historical eras, and develop new identities in virtual worlds. Not surprisingly, the United States Army, The American Homebuilder’s Association, radical Evangelists, and even Spanish terrorists among others have begun funding games to popularize their ideologies. I believe that educators and scientists, *particularly those with a vested interest in public education* need to also take up games as a medium for pushing their agendas. Space exploration and science learning more generally are an ideal fit for this area.

Since the days of science fiction popular media has been used to help the public understand important ideas in science. For generations, the Bell Labs science films, developed by Hollywood talent (Jack Warner, Frank Capra, Chuck Jones) in conjunction with Bell Labs for prime time television consumption were used in classrooms across the country. Developed in response to Sputnik, its creators called the project Operation Frontal Lobe. More recently, NOVA and Bill Nye have filled similar functions. With widespread reports of students’ interest in school decreasing and increasing gaps between scientists’ understandings of the world and those of the public sector, we need another Operation Frontal Lobe. But if you wanted to build an operation frontal lobe with today’s media, I believe you would use video games.

Games are now pushing the envelope of consumer grade artificial television, real time 3D rendering, and real-time physics. As our research team demonstrated with *Supercharged!* even a team of undergraduate developers working with game development tools can create interesting science education software that helps build complex conceptual understanding. Working with NASA Medal of Science winner John Belcher, we created a robust prototype that produced impressive learning gains in Boston classrooms. With sufficient resources and real partnerships across academics and industry – like we saw with the Bell Labs science films – we can do even better.

A number of popular entertainment games skirt on the boundaries of physics, science, and space exploration, suggesting that creating a game that is both fun and educational. Sid Meier’s Alpha Centauri asks what would happen if a flight to colonize another planet crashed. Players build space stations, research future technologies (such as nanotechnologies) and think about the different values behind different civilizations. Mind Rover allows players to build and battle artificial robots through programming Artificial Intelligence algorithms. Sim Station Tycoon, a less ambitious game following the popular “tycoon” model, allows players to build space stations on hypothetical planets.

These are good games that point the way toward games that embodied cutting-edge science, but only through a real collaboration by NASA scientists, learning scientists, and top game developers can we create something with broad impact. While working on the games-to-teach project MIT, I helped develop Hephaestus, a game prototype (which never was built) but illustrated what one could do with such games.

Working with Henry Jenkins and Woodie Flowers (who helped create FIRST, the international robotics competition), I co-designed a game around the colonization and exploration of other planets. The idea of this science fiction game is that different countries and multi-nationals are in a race to explore (and secure resources on) other planets. Working in teams players design and construct virtual robots that terraform the planet. Players' robots must deal with the extreme environmental conditions of these planets and expeditions must be planned carefully in order to manage fuel consumption and so on.

Drawing on the mechanics of games like Everquest, the idea is that players would develop build and upgrade their robots over hours of use. Building on these role playing game conventions, players would start simply and be able to research and add new parts, through design tools. Engaging in the practices of aeronautical and robotics engineers, they might learn basic physics and engineering, as well as more complex design practices. A driving idea behind the game is that expert and novice players could play together on teams, allowing apprenticeship and collaborative learning to occur, just as it does in the FIRST competition.

While this game exists only in paper (and in mock-ups), I believe it suggests the untapped potential of the game for informal learning. Core to this vision is that learning scientists, game designers, and or scientists cannot go at this alone. Game designers understand interactivity and engagement, learning scientists understand human cognition, identities, and learning, and scientists understand their field, as well as critical learning issues in their field. Together, we can provide a healthy alternative to the other ideological groups producing games.

Although these ideas may seem far-fetched, recent innovations in development tools, support infrastructure, and research make such ideas possible. Through the Games and Professional Practice Simulations Group, we are building the research base and industry, government, academic partnerships that such games require. The Education Arcade is working with game publishes and press to acknowledge this emerging market and publicize the work of groups like the Home Builder's Association. We believe that a consortium of developers and institutions can make these "serious games" a reality.

For more information:
The Education Arcade: http://www.educationarcade.org/
Hephaestus: http://www.educationarcade.org/gtt/Hephaestus.htm

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