THE AUSTRALIAN NATIONAL UNIVERSITY

# Playing at Reality

## Exploring the Potential of the Digital Game as a Medium for Science Communication

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October, 2004

A thesis submitted for the degree of Doctor of Philosophy of
The Australian National University

Centre for the Public Awareness of Science
Faculty of Science

# Declaration

I certify that this thesis does not incorporate without acknowledgment any material previously submitted for a degree or diploma at any university and that, to the best of my knowledge and belief, it does not contain any material previously published or written by another person except when due reference is made in the text. The empirical work described within was not carried out with any other person.

Alexander Lewis Aitkin

# Acknowledgements

With thanks to Sue Stocklmayer and Chris Bryant – respectively my supervisor and adviser at the Centre for the Public Awareness of Science – for guidance and comments on my drafts.  And with special thanks to my parents, to whom I dedicate this work.

# Abstract

Scientific culture is not popular because the essential nature of science – the models and practices that make it up – cannot be communicated via conventional media in a manner that is interesting to the average person. These models and practices might be communicated in an interesting manner using the new medium of the digital game, yet very few digital games based upon scientific simulations have been created and thus the potential of such games to facilitate scientific knowledge construction cannot be studied directly. Scientific simulations have, however, been much used by scientists to facilitate their own knowledge construction, and equally, both simulations and games have been used by science educators to facilitate knowledge construction on the part of their students. The large academic literatures relating to these simulations and games collectively demonstrate that their ability to re-create reality, model complex systems, be visual and interactive, engage the user in the practise of science, and to engage the user in construction and collaboration, makes them powerful tools for facilitating scientific

knowledge construction.  Moreover, the large non-academic literature discussing the nature of digital games (which are themselves both simulations and games) demonstrates that *their* ability to perform the above tasks (i.e. to re-create reality, model complex systems, and so forth) is what makes them enjoyable to play.

Because the features of scientific and educational simulations and games that facilitate knowledge construction are the very same features that make digital games enjoyable to play, the player of a scientific-simulation-based digital game would be simultaneously gaining enjoyment and acquiring scientific knowledge.  If science were widely communicated using digital games, therefore, then it would be possible for there to be a popular scientific culture.

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# Prologue

The first ever video game was designed by William Higinbotham, a physicist working at the Brookhaven National Laboratory (BNL) in Suffolk County, Long Island, New York. BNL hosted both a particle accelerator and a small nuclear reactor designed for research. Because some residents of Suffolk County felt that the laboratory posed a threat to their community, BNL began to host an annual 'visitor's day' in order to generate positive public relations. The idea was that visitors would see the harmless research being conducted there and feel more easy.

> One day, Higinbotham had an idea to entertain the visiting guests who were bored by the spinning reels and blinkenlights of the mainframe computers. 'I knew from past visitor's days that people were not much interested in static exhibits so for that year, I came up with an idea for a hands-on display – a video tennis game.'. . . The game he created was called *Tennis For Two* – and it was the first recorded iteration of the game that later evolved into *Pong*. Featuring a blip of electronic light, this revolutionary tennis simulation was programmed in 1958 by Higinbotham and his team using trajectory paths on an analog computer. The team also added two control boxes, each with a knob to control the ball and a 'serve' button –

> likely the first implementation of a 'joystick' in an interactive game. *Tennis For Two* was displayed on a 5' monochrome oscilloscope screen and debued in the Instrumentation Division display that same year. People waited hours to play (Burnham, 2001, p. 28).

The story behind the development of the first ever digital-computer-based simulation-game[♣] is in certain respects very similar. When the Massachusetts Institute of Technology (MIT) received its first PDP-1 computer in the autumn of 1961, a group of computer science students began devising a plan for how to show off its capabilities, and particularly, how to show them off to the non computer-literate visitors who would come during MIT's annual open-house day.

> **"You Mean That's All It Does?"**
> When computers were still marvels, people would flock to watch them still at work whenever the opportunity arose. They were usually disappointed. Whirring tapes and clattering card readers can hold one's interest for only so long. They just did the same dull thing over and over; besides, they were obviously mechanical – at best, overgrown record changers – and thus not mysterious. The mainframe, which did all the marvellous work, just sat there. There was nothing to *see* (Graetz, 1981/2001).

The students wanted to develop a computer program that could demonstrate the abilities of the new computer, and a good demonstration program, they decided, ought to satisfy three criteria:

- It should demonstrate as many of the computer's resources as possible, and tax those resources to the limit.
- Within a consistent framework, it should be interesting, which means every run should be different.

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[♣] Though not the first ever digital computer game (a version of Tic Tac Toe), which may have run on the first ever digital computer, EDSAC, in 1949, but which definitely ran on another early computer, the Pilot ACE, in 1950 (Michie, 2002).

- It should involve the onlooker in a pleasurable and active way – in short, it should be a game.

*Spacewar!*, designed by MIT students Steve Russell, Peter Samson, Dan Edwards, Jim Graetz, and others in 1961-62, was the result. This game involved players controlling from two to five spacecraft, each with limited fuel, 'torpedoes', and the ability to jump into 'hyperspace', battling each other within the gravitational field of a sun. The acceleration of the ships was realistically inertial in that it took time to build up speed, and to slow down one had to turn one's ship around and thrust in the opposite direction. The background of the game was a realistic depiction of the entire night sky between 22.5N and 22.5S, with the stars shown at something close to their relative brightnesses (Graetz, 1981/2001). *Spacewar!* was a massively popular game:

> . . . the handful of people that copied *Spacewar* off MIT's PDP-1 gave it to their colleagues, who shared it with their students, who spread it among their fellow programmers, until, by the mid-sixties, there was a copy of *Spacewar* on every research computer in America, as well as hundreds of personal variations on the source code and millions of dollars of lost-time cost to academia and the military-industrial complex. . . . *Spacewar* was so pervasive that it's hard to overestimate its impact upon the computer culture of the time. Virtually every young programmer in the sixties played it. (Herz, 1997, pp. 7-8)

It is in one sense remarkable, and yet in another sense completely natural, that the first ever analog-computer-based simulation game and the first ever digital-computer-based simulation game were independently created with the same goal in mind: to introduce computer technology to non-experts. It is remarkable because digital games are regarded as being trivial and unserious while in their early days computers were seen as very serious indeed. It is completely natural because computers facilitate game playing so well, and also because games are so popular. *Tennis for Two* and *Spacewar!* turned the computer from an alien and forbidding device into something popular and enjoyable that even children could relate to. Can digital games also turn *science* from something alien and forbidding into something popular and enjoyable that even children can relate to? It will be the business of this thesis to find out.

*Sully early noted that, remarkably, young children could make the play situation and reality coincide.  He described a case where two sisters, aged five and seven, said to each other, 'Let's play sisters.' They were playing at reality.*

*(Vygotsky, 1978, p. 94)*

CHAPTER ONE

# Introduction

Say the word *culture* to someone and they will think of music, dance, art, novels, food and fashion.  But of science?  No.  While the creative world might be divided into Two Cultures as C.P. Snow suggested, one of these cultures exerts far more influence upon people's experiences and attitudes than does the other.  The reason for this is easy to discern.  One of these cultures may be listened to, danced, viewed, read, eaten and worn, and as such possesses a direct human significance.  The other culture, by contrast, lies hidden behind the walls of university libraries, trapped within imposing volumes and is expressed using symbols and words that have meaning to only a very few.  Of course, science does exert a large (and increasingly large) effect upon society through its application within technology, yet it is ultimately technology rather than science that becomes incorporated within culture.

For both negative and positive reasons it is desirable that this state-of-affairs does not persist, and that a popular scientific culture should come into being that exerts as much influence upon the social world as does the present popular *artistic* culture. It is undesirable that scientific culture should remain largely unperceived and unpopular because, while a large and increasing proportion of social capital is consumed by scientific research♣, the knowledge created as a result of this research is of little direct use to most of the people who make up society. It thus represents an underutilized and wasted resource. The lack of public awareness of science is also undesirable because the direct use to which scientific research is put may potentially be harmful to both people and their environment. The business sector, which both funds and performs the majority of scientific research♦, does so in the interests of profit rather than social wellbeing, and should a technology be developed which is *potentially* both profitable and harmful (e.g. genetically modified foods) then only a scientifically aware public has the power to act in its own interest and to control the application of this technology (cf. Levidow, 2002; Pusztai, 2002).

Treating the matter from a positive perspective, it is desirable that science should be popular because the worlds that scientists discover are fascinating places and because the new understandings that science generates have the power to radically (and thus interestingly) alter people's perceptions of their experience. It is also desirable that

♣ In 2001, OECD countries allocated approximately 2.3% of overall GDP to scientific research and development, and this expenditure increased at a rate of 4.7% between 1995 and 2001 (OECD, Science, Technology and Industry Scoreboard, 2003).

♦ More than 63% of funding for scientific research (in OECD countries in 2001) came from the business sector, and since the mid 1990s 70% of research has been performed by the business sector (OECD, Science, Technology and Industry Scoreboard, 2003).

scientific culture should be popular because scientific knowledge may often be used to solve problems within daily life and because knowing how to solve problems scientifically can make them easier to solve.

While the popularity of science has waxed and waned over time it has never approached the popularity of the arts and humanities, and this might lead one to suspect that the very nature of scientific knowledge precludes it ever gaining such popularity. Certainly, it is difficult to imagine a time when the popular-science sections of book stores will take up half their shelf-space, or when half of the programs shown on television are science related. Even if such a time did arise, moreover, much of the content of popular-science books and television shows is usually not directly concerned with scientific models. Instead, within these contexts science is often sensationalised or humanised in order to make it more interesting for laypeople. There are other ways to communicate science apart from through books and the television, however, and if some means could be found to make the construction of scientific knowledge intrinsically enjoyable then science could be more widely popular. The central hypothesis tested in this thesis is that digital games (computer games, video games, arcade games) based upon scientific simulations can make science intrinsically enjoyable.

Few digital games based upon scientific simulations exist, and thus it is not possible to test the above hypothesis directly. A voluminous collection of academic writings deals with the use of simulations by scientists, however, and these writings provide a detailed insight into the attributes of simulations that make them such useful scientific tools.

Additionally, a large and growing body of non-academic writing discusses the nature of digital games and those attributes of digital games that make them enjoyable to play. Now, if it could be shown that those attributes that make simulations useful for scientists are the same attributes that make digital games enjoyable to play then it would also have been shown that games based upon scientific simulations make the construction of scientific knowledge intrinsically enjoyable.

Chapter Two of this thesis discusses the nature of science communication and shows why existing mass media forms are unable to make what is essential to science intrinsically enjoyable.  Chapter Three discusses the nature of digital games and shows what it is that makes them enjoyable to play.  Chapters Four, Five and Six establish the natures of scientific simulations, educational simulations, and educational games, and show how these software artefacts facilitate the construction of scientific knowledge. Finally, Chapter Seven identifies those attributes of scientific simulations that make them useful for scientists, that are possessed by digital games, and that make digital games enjoyable to play.

*. . . the achievements of science become more numerous, more inspiring, more divorced from the little corner of common sense familiar to all of us . . .*

*(Chorafas, 1965, p. xv)*

CHAPTER TWO

# Science Communication and Media

The purpose of this chapter is to discuss the nature of science communication and to show why existing mass media forms are unable to make science intrinsically enjoyable. The nature of science communication will be explicated through an analysis of the meanings of the terms *science*, *communication*, and *science communication*. The limitations of the existing mass media will be explicated through an analysis of the nature of symbols and icons as forms of representation. As a result of these analyses it will be hypothesised that the new mass medium of the digital game is capable of communicating what is essential to science in ways that are enjoyable for lay people, and a means of testing this hypothesis will be suggested.

# Science

Whole books could be, and have been (e.g. Thomson, 1911), written on the nature of science and thus the discussion of science presented below is necessarily brief and incomplete. That being said, science may be understood both as a method of learning about the natural world (Checkland, 1976/1991) and also as that which has been learned via this method. As a learning method, science consists of four well-known steps:

1. Observation of a physical system.
2. Formulation of a hypothesis (which might take the form of a mathematical model) that attempts to explain observations of the system.
3. Prediction of the behaviour of the system on the basis of the hypothesis (e.g. by obtaining outputs from the model for a given set of inputs).
4. Performance of experiments to test the validity of the hypothesis (Naylor, Balintfy, Burdick & Chu, 1966).

Depending upon the particular discipline within which a scientist works and the particular disposition of that scientist, however, she or he might spend the majority of her or his time engaged in some of these activities and little or none of it engaged in others. There are, for example, scientists who engage in no experimental work at all and mainly engage in theory and model construction, while others engage predominantly in the collection and description of objects. No matter what activities a scientist chiefly engages in, though, there is generally an element of *puzzle-solving* to their work.

> Bringing a normal research problem to a conclusion . . . requires the solution of all sorts of complex instrumental, conceptual, and mathematical puzzles. The man who succeeds proves himself an expert puzzle-solver, and the challenge of the puzzle is an important part of what usually drives him on. . . . [What] challenges him is the

> conviction that, if only he is skilful enough, he will succeed in solving a puzzle that no one before has solved or solved so well. Many of the greatest scientific minds have devoted all of their professional attention to demanding puzzles of this sort. On most occasions any particular field of specialisation offers nothing else to do, a fact that makes it no less fascinating to the proper sort of addict. (Kuhn, 1970, pp. 36-38)

Puzzle-solving thus constitutes a core practice of science, and one cannot truly be said to have communicated what is essential to science if one's communication does not somehow facilitate this practice.

Just as there are certain activities in which scientists engage, so too there are certain kinds of knowledge that are constructed as a result of these activities. Some of this knowledge is descriptive (e.g. facts of various kinds), and some of it is *how-to* knowledge (such as that often associated with technological development and medicine). The type of knowledge that is most commonly associated with scientific work is, however, the theory or model. Theories and models can take the form of mathematical equations, of diagrams, of computer-based simulations, and they can also take the form of mental models that scientists develop 'in their heads'. Whatever the particular form that a scientific theory or model takes, this knowledge must finally be published before it can be used by other scientists.

> Research is complete only when the results are shared with the scientific community. Although such sharing is accomplished in various ways, both formal and informal, the traditional medium for communicating research results is the scientific journal. (American Psychological Association, 1994, p. 1)

Science communication of a formal kind is thus an inherent part of scientific activity.

## Science and the Unfamiliar

It has been observed that the boundary between the natural and artificial (i.e. the technological) is entirely political. We fear technology that is unfamiliar (such as biotechnology) but welcome other technology that is familiar (such as the contact lens or the ballpoint pen) and we do not think of the familiar as technology at all (Haraway, 1991; Travers & Decker, 1999). A similar situation exists with respect to science: when scientific knowledge becomes familiar it ceases to be considered as *scientific*. Psychology has always had trouble being recognized as a science for this reason:

> Few of us would be presumptuous enough to attempt, untutored and on our own, to provide explanations of gravity, exploding stars, or chemical reactions. More of us might embark upon explanations of historical events, of political change, or of economic trends – but, confronted by an expert who possessed appropriate academic credentials, we would usually defer to her superior knowledge and experience. Not so in psychology. In this field we encounter – and with some justification – the argument that all of us live and grow in human societies and that, in the process, much that is true is learned about psychological phenomena. (Krech, Crutchfield & Livson, 1974, p. xv)

It is no coincidence that physics and chemistry, the areas of study most closely associated with the term *science*, are also the sciences whose subject matter, experimental procedures, and language are most unfamiliar to the average citizen.

One consequence of the general unfamiliarity of science is that science, unlike the arts and humanities, is frequently understood as a monolithic (i.e. homogeneous, undifferentiated) enterprise. So for example, novelists, musicians, dancers etc. are usually referred to as such within the news media and not in terms of the meta-categorization of *artist* whereas, by contrast, a physicist or biologist is more likely to be referred to as a *scientist*. Similarly, the works and methods of artists (e.g. novelists, musicians, dancers) are understood to be very different whereas, by contrast, it is generally believed that there is one *scientific method* shared by all scientists. This is true only in the abstract, however. Concretely speaking, the “problems, methods, styles of observation, standards of proof and experimental design” of scientists are very different from one science to the next (Rose, 2001, p. 113), and thus to properly understand the ‘nature of science’ one must ultimately gain some experience with many different particular sciences.

## Communication

An early and influential definition of the term communication was provided by Weaver (1949, pp. 3-4), who stated:

> The word *communication* will be used here in a very broad sense to include all of the procedures by which one mind may affect another. . . . Relative to the broad subject of communication, there seem to be problems at three levels. Thus it seems reasonable to ask, serially:
>
> LEVEL A. How accurately can the symbols of communication be transmitted? (The technical problem).
>
> LEVEL B. How precisely do the transmitted symbols of communication convey the desired meaning? (The semantic problem).
>
> LEVEL C. How effectively does the received meaning affect conduct in the desired way? (The effectiveness problem).

To summarise Weaver’s model of communication, he proposed that communication is a process involving the transmission, from one mind to another, of symbols that convey meaning, with the intention that the conduct of the receiving mind shall be affected.

While certainly the most influential extant model of communication, Weaver's model does have some problems. Its use of the term *mind*, for example, is somewhat restrictive: *information processor* would be a more suitable term, encompassing not just human beings but also other animals and computers. The idea that communication is transmission from one mind to another is problematic for two reasons. First of all, communication need not only occur between two individuals. It can occur from one individual to many (as in a radio broadcast), from many to one (as in an election), and from many to many (as in an online multiplayer computer game). Moreover, communication need not only occur *from* one individual *to* another. Communication can be two-way, or interactive, where information is sent by those involved to each other such that all participants are both senders and receivers.♣

## Level A

The use of the term *symbols* within Weaver's definition of communication is problematic since, as he states, amongst the procedures of communication are "not only written and oral speech, but also music, the pictorial arts, the theatre, the ballet, and in fact all human behaviour" (p. 3), and certainly not all of these communication procedures involve symbols. Looking at the matter abstractly, communication involves the transmission of information. Information takes the form of patterns within some physical medium that refer to something, and this process of referring to or representing something has traditionally been understood to be able to occur in three different ways

♣ The meaning of the term *interactive* has been the subject of a long (and still continuing) debate. See Rafaeli (1988) and Jensen (1998) for lucid and in-depth discussions.

(Peirce, 1868, 1894). A representation can take a form that corresponds to or resembles its referent (as does a photograph or sound recording), and such a representation is known as an *icon*. A representation can take a form that is correlated in some way with its referent (as is a yawn to sleepiness, or as is a red light with decelerating traffic), and such a representation is known as an *index*. Finally, a representation can take a form that possesses no physical relation at all to its referent, and such a representation is known as a *symbol*.

What makes something a form of information is not simply that it is a representation, however, but also that it is to some degree *unexpected*. In fact, from the perspective of information theory the degree of informativeness of a message is equal to its degree of unexpectedness (Shannon & Weaver, 1949). That this must true becomes clear when we consider that if we know exactly what a person is about to say then their message is totally uninformative. Also, if we know exactly what a person is about to say then their saying it will not alter our behaviour, and it must do this if communication is to have occurred (see Level C below). To have received information, then, is to have received symbols, indices, or icons and to have *learned* something from them.

## Level B

The role that meaning plays within Weaver's definition is another of its problematic aspects. On this *semantic problem* Gibson (1966) notes:

> The traditional or common-sense explanation of how one man conveys information to another is simply that men have ideas, and that ideas are transmitted. The idea is said to be 'expressed' in

> language, the words ‘carry’ the idea, and the idea is then ‘grasped’ or ‘taken in’. . . . It is hardly necessary to point out that this is no explanation at all. (p. 93)

On this same point, Reddy (1979) concludes that:

> . . . no one *receives* anyone else’s thoughts directly in their minds when they are using language . . . Nor can anyone literally ‘give you an idea’ . . . Language seems rather to help one person to construct out of his own stock of mental stuff something like a replica, or copy of someone else’s thoughts – a replica which can be more or less accurate, depending on many factors. If we could indeed send thoughts to one another, we would have little need for a communications system. (Reddy, 1979, p. x)

The idea that thoughts, ideas, and meanings can be transferred from one mind to another via language exists as part of a broader conception of human knowledge construction that Piaget (1970/1983, 1973) labels as *empiricism*. According to this conception, the human mind is a kind of structureless void, a ‘blank page’, and we come to have knowledge of the objective world both directly via our sense organs, and indirectly via language. Together, perceptually based and linguistically based knowledge form a functional copy of the objects and processes that make up the objective world (Piaget, 1970/1983).

## Constructivist Learning Theory

With the development of psychological research within the twentieth century, empiricism has largely fallen out of favour within psychology and has been supplanted by a different, *constructivist* conception. Within this conception:

- Knowledge is not passively received either through the senses or by way of communication. Rather, knowledge is actively constructed by the cognising subject (Glaserfeld, 1991).

- Knowledge is constructed in order to improve the success or effectiveness of a person's actions, not in order to discover an objective reality (Glaserfeld, 1991).
- Knowledge of objects is constructed as a result of direct physical interaction with them (Piaget, 1970/1983). It is constructed within the cyclic process of a person initiating goal directed action and then being affected by the results of that action (Dewey, 1899/1966, 1916; Piaget & Inhelder, 1969).
- Knowledge is constructed as a result of linguistically-mediated socially-assisted practical activity (Vygotsky, 1978).

People do not gain new knowledge simply by copying what they see or are told and then adding these copies to their existing collection of knowledge. Rather, they use their existing knowledge structures to make sense of new information, while at the same time this new information changes the existing knowledge structures, a pair of processes known as assimilation and accommodation (Piaget & Inhelder, 1969). The construction of new knowledge thus depends upon a degree of harmony existing between the information to be added to one's knowledge structures and the state of those knowledge structures themselves. If too great a mismatch exists between them then one will not be able to understand a given piece of information, nor add it to one's existing knowledge. Only when new information gives rise to an active reconstruction of one's knowledge has learning (or communication) taken place (Piaget, 1970/1983). This process of knowledge construction is iterative: it occurs step by step as simpler knowledge structures are combined to form more complex structures, and always so that assimilation and accommodation are roughly in balance (Piaget, 1970/1983; Piaget & Inhelder, 1969).

Knowledge construction is not usually an end in itself but is rather a byproduct of goal-directed activity (Dewey, 1916). People construct knowledge regarding the objects and processes that they are interacting with as they carry out some task involving those objects and processes. The information that they use to amend their knowledge structures is thus not gained through passive recording but rather through physical interaction and manipulation (Piaget, 1970/1983). When a person successfully accomplishes a goal, his or her existing knowledge structures are able to assimilate this experience: they are in harmony with it. By contrast, when a person fails to accomplish a goal his or her existing knowledge structures must accommodate this unexpected occurrence: they must change as a result. The end result of this alteration is that the person is better adapted to his or her environment, enabled to act more effectively and to more readily accomplish future goals.

Knowledge construction should not be conceived as an isolated, individualistic phenomenon. Rather, knowledge-construction processes essentially depend upon interaction and cooperation with others. This dependence is illustrated by the fact that a person assisted by others is able to solve problems and carry out tasks (thus acquiring knowledge) that would be too difficult for them without such assistance. Individuals also depend upon other members of their social group to assist them in constructing meanings for words (Vygotsky, 1978).

The *experiential learning model* (Kolb, 1984; Kolb & Fry, 1975), depicted in Figure 1, is a four-stage model of human problem solving and knowledge construction that summarises some of the key constructivist ideas discussed above. Although the various stages of the model have been numbered and placed in a certain order, in practice a person will constantly jump between these stages during the solution of any given problem. Nonetheless, the different stages of problem-solving and knowledge construction are logically related to each other as shown.

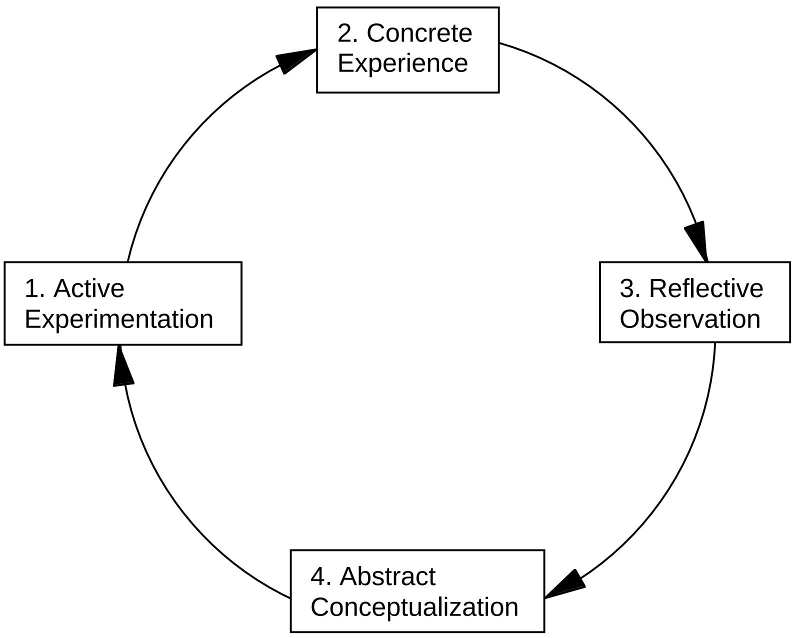


**FIGURE 1** – The experiential learning model (Kolb, 1984; Kolb & Fry, 1975).

To elucidate this model: as one attempts to complete some task, solve some problem, or realise some goal, one engages in active experimentation (1). In the process of this experimentation one gains direct, sense-based experience of the problem area (2). The new experience that one has gained is then reflected on (i.e. thought about) to some degree, meaning that one's existing knowledge structures are applied to it (3). As a result of this reflection, one's existing abstract knowledge structures (i.e. one's theories of how the problem situation functions) either assimilate the experience or accommodate themselves to it (4). If knowledge structures are changed then new predictions of the problem area's behaviour will be made and new experiments can be designed to test these predictions (1).

The experiential learning model illustrates the interdependence of experiential and conceptual knowledge. One's interaction with the environment is guided by one's conceptual knowledge and, likewise, one makes sense of one's experience through the process of interpreting it via that conceptual knowledge. Conversely, the sole purpose of one's conceptual knowledge is to guide one's problem-solving activities and, moreover, this conceptual knowledge would possess no meaning in the absence of some sense-based experience to be framed and interpreted by it. The relationship between experiential and conceptual knowledge is thus central to knowledge construction (Kolb & Fry, 1975).

The importance of both experiential and conceptual knowledge for knowledge construction may be demonstrated with the help of two examples. The first example illustrates the importance of conceptual information when attempting to understand a concrete, sense-based experience: namely, attempting to understand the Mondrian painting depicted in Figure 2.

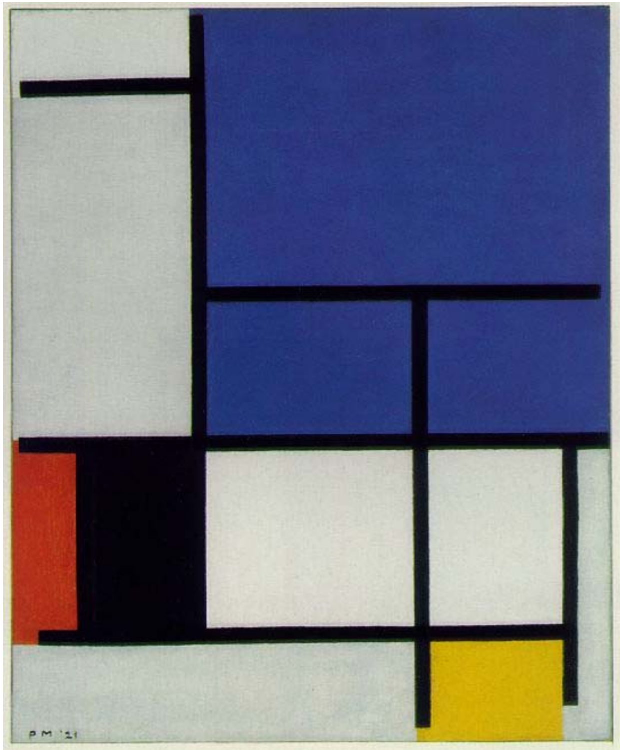

**FIGURE 2** – Piet Mondrian, Composition with Large Blue Plane, Red, Black, Yellow, and Gray, 1921. (© 2003 Artist Rights Society. Scan by Mark Harden, www.artchive.com.)

There are a number of activities that one could engage in if one wished to better understand this painting by Mondrian. For example, one might view others of his paintings from this body of work, one might study the works of other constructivist♣ painters such as Kasmir Malevich, Aleksandr Rodchenko, Vasily Kandinsky, and Paul Klee, or one might read the words of Mondrian himself regarding his aims and intentions. Pursuing this third option one could learn that Mondrian's aim in painting such works was to "express relationships plastically through oppositions of color and line", and that he believed "form and color are weakened by curvature and by the corporeality of things" (Mondrian, 1919/1992, p. 282). Reading Mondrian's words

♣ In this context, *constructivist* refers to a particular school of abstract painting.

provides us directly with an abstract knowledge that is helpful in interpreting his painting, a knowledge that we could never gain simply by viewing a single one of his paintings, and a knowledge that we could not generate for ourselves even by viewing many such paintings.

Consider in contrast now what it would mean to understand the following equation:

$$\Delta_p w_{ji} = \eta(t_{pj}-o_{pj})i_{pi}= \eta\delta_{pj}i_{pi}$$

If this equation is unfamiliar (as it was intended to be) then it is also almost completely meaningless. Certainly, if one were given values for the various terms on the right one could calculate a value for the change in W, but this would still not be at all revealing as to what the equation actually represents.♣ Thus, communicating this equation to a person who does not know the meanings of its terms is pointless. In this regard Dewey notes that:

> The logically formulated material of a science or branch of learning, of a study, is no substitute for the having of individual experiences. The mathematical formula for a falling body does not take the place of personal contact and immediate individual experience with the falling thing. . . . A symbol which is induced from without, which has not been led up to in preliminary activities, is, as we say, a *bare* or *mere* symbol; it is dead and barren. . . . It is not a reality, but just the sign of a reality which *might* be experienced if certain conditions were fulfilled. (Dewey, 1902/1956, pp. 20-24)

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♣ The standard delta rule for learning by neural networks. "The rule for changing weights following presentation of input/output pair p where $t_{pj}$ is the target input for the jth component of the output pattern for pattern p, $o_{pj}$.is the jth element of the actual output pattern produced by the presentation of input pattern p, $i_{pi}$ is the value of the ith element of the input pattern $\delta_{pj} = t_{pj}-o_{pj}$, and $\Delta_p w_{ji}$ is the change to be made to the weight from the ith to the jth unit following presentation of pattern p." (Rumelhart, Hinton, & Williams, 1986, p. 322)

One can thus not be truly said to understand the above equation, and one can certainly not make any use of it, unless one knows how it relates to the physical world, and knowing this ultimately means possessing experiences that correspond to the individual terms.  Just as abstract conceptual knowledge is essential when attempting to make sense of direct experience, therefore, direct experience is likewise essential when attempting to make sense of abstract conceptual knowledge.

It is important to note, at this point, that the above discussions regarding knowledge construction have focused upon construction of a particular type of knowledge, known as declarative knowledge.  Declarative knowledge is knowledge *about* things.  There is another type of knowledge, however, that is equally important from the point-of-view of problem solving and the accomplishment of one's goals.  This second type of knowledge is known as procedural knowledge and is knowledge of *how to* do things (such as think logically, ride a bicycle, form a meaningful sentence) (Anderson, 1983).  Declarative knowledge and procedural knowledge are similar in that they are acquired through action and interaction with things.  One gains declarative knowledge when one learns *about* the thing one is interacting with, while by contrast, one gains procedural knowledge when one learns *how to* interact with that thing.  Through direct physical interaction with a bicycle, for example, one can discover its height, weight, state of repair, etc, and one can also learn how to ride it.  An important difference between declarative and procedural knowledge is, however, that the former is easily communicable whereas the latter is not.  That is, while it can be quite straightforward to learn *about* things via communication, it is much harder to learn *how to* do things via communication. Skill-based knowledge is not easily translated into words or pictures. The best way, and ultimately the only way, to become proficient in some activity is to practise it. It is perhaps because of the difficulties involved with communicating procedural knowledge that this form of knowledge is so often neglected in discussions regarding communication, yet communication of procedural knowledge is both desirable and necessary in the context of science communication. Having earlier determined that science consists both of activities and what is learned from those activities, science communication must at least to some degree be concerned with communicating the actual activity of science itself.

## Communication from a Constructivist Perspective

Viewing communication from a constructivist as opposed to an empiricist perspective, one no longer sees it as a process whereby meanings, thoughts, or ideas are transmitted from one mind to another. Instead, communication is understood as a process whereby transmitted information stimulates the construction of new knowledge from the existing knowledge present in the receiver's mind and memory, and communication will be deemed successful from the sender's point-of-view to the degree that the knowledge constructed by the receiver takes the form of that possessed by the sender. Senders have partial control over the final form of this knowledge (exercised when they choose to send one message rather than another), receivers have partial control over this final form (exercised when they choose to attend to, and reflect upon, one message over another), while some proportion of the final form of this knowledge is beyond the control of either group, being a function of the degree of similarity of their knowledge structures. That is, even if a receiver works hard to understand, and a sender works hard to be understood, if the initial difference between their knowledge structures is too great then no amount of work on either side will rectify the situation.

## Level C

The third problem that Weaver (1949) identified in his definition of communication was "How effectively does the received meaning affect conduct in the desired way?" (p. 4). This question raises two further questions, namely, "what constitutes conduct", and "desired by whom?" With regard to *who* decides in what ways the receiver's conduct is to be changed, it is true not only that a person sends information in order to affect the receiver's conduct, but also that a person seeks out information in order to affect his or her own conduct (Wijngaert, 1999). The relative power of the roles of sender and receiver in determining both the information received and the conduct that results from receiving it varies from one situation to the next, and, following both Dewey (1916) and also popular usage, I define educational situations as those within which the sender has the greater power, and communicational situations as those within which the receiver has the greater power.

On one level of their use, Dewey recognized that the terms education and communication have similar meanings. So for example, across three paragraphs in his book *Democracy and Education* he makes the following statements:

> Society exists through a process of transmission. . . . This transmission occurs by means of communication. . . . Without this communication . . . social life could not survive. (Dewey, 1916, p. 4)

> Education, in its broadest sense, is the means of [the] social continuity of life. . . . The primary ineluctable facts of the birth and death of each one of the constituent members in a social group determine the necessity of education. (Dewey, 1916, p. 4)

Dewey believed, however, that while all communication is educative (and vice versa), the *social activity* we call education involves the deliberate attempt on the part of one person/group to enlarge and change the experience of another person/group so as to form within them "desirable intellectual and emotional dispositions" (Dewey, 1916, p. 212). As exemplifying this idea, Hirst and Peters (1970) propose that:

> . . .'educating' people suggests a family of processes whose principle of unity is the development of desirable qualities in them. . . . In formulating aims of education we are attempting to specify more precisely what qualities we think it most desirable to develop. (p. 19)

By contrast, for Dewey communication (in its specialised sense) meant:

> . . . that we simply put a fact, a truth, a statement, objectively before another person, and leave it to him entirely to interpret that, to estimate its worth and value, and so to determine completely for himself what kind of response he will make. (Dewey, 1899/1966, p. 55)

Within educational contexts the sender of information has both a plan for what the receiver will do with the information and some degree of power in ensuring that this plan is realised. Students in a school, regardless of whether they are personally interested in the subject matter being taught or not, must make some effort towards learning it or else they will "take a scolding, be held up to general ridicule, stay after school, receive degradingly low marks, or fail to be promoted" (Dewey, 1900/1956, p. 29). In communicational contexts, by contrast, the sender of information has no such power. The publishers of books, magazines and newspapers, the producers of films, radio and television shows, and the makers of digital games, can only send their products out into the marketplace and hope that they are purchased. In communicational contexts it is the receivers (consumers, users) who decide what information they will receive and what they will do with it.

This distinction being made here between education and communication may not be a universally agreeable one. Professor John Beetlestone, retired Director of Cardiff's *Techniquest* Science Centre has proposed, for example, that "We're in education, we're serious, but first and foremost we're part of the leisure and entertainment industry" (Shortland, 1987, p. 213). Within the perspective of this thesis there is no contradiction in the above statement if it is understood to mean that *Techniquest* runs educational programs alongside its primary business, which is entertainment; or that education may be fun, and thus entertain*ing*; or that entertainment may facilitate knowledge construction. If, however, what Professor Beetlestone meant was that *Techniquest* was simultaneously, and in exactly the same ways, *in* both education and entertainment, then this would stand in conflict with the distinction between education and communication being proposed here. The phrasing of Professor Beetlestone's statement does, however, tend to support the idea that he saw education and entertainment as standing in opposition to one another, and while many wish it were otherwise♠ this point of view does also appear to be a dominant one within both educational and entertainment-industry contexts.

♠ See www.afaweb.org/programs/df99_competing.asp for a discussion by museum directors regarding whether it must be education *versus* entertainment.

The problem of effectiveness – the problem of ensuring that a sent message will affect the behaviour of the receiver in a particular way – differs between the contexts of education and communication, and these contexts are treated separately below.

## Effectiveness Within Education

Within various of his books and lectures (cf. Dewey, 1899/1966, 1900/1956, 1902/1956, 1916, 1938) philosopher and educator John Dewey provided a thoroughgoing critique of the effectiveness of traditional education (and particularly science education). Its substance (described in detail below) was that traditional science education was ineffective at providing students with a deep understanding of science because it did not provide them with experiences, because it did not allow them to interact with phenomena, and because they were not engaging in personally-relevant problem solving.

*Experience* was of particular concern to Dewey, and by this term he meant the process of purposefully acting upon the world and consequently being acted upon by the world. For Dewey, the purpose of education is to reconstruct and reorganise the experience of the student, to transform the quality of this experience in order to add to its meaning, and to increase the student's ability and power to direct and control the course of his or her subsequent experiences. Dewey counterposed this goal with "the encyclopaedia or dictionary ideal" of traditional education (Dewey, 1899/1966, p. 58), and suggested that this goal of acquiring information should be subordinated to the goal of stimulating positive interactions between students and their environment so as to develop each student's experience.

Ideally, argued Dewey, education should take as its beginning the ordinary experiences of the student and from here should seek to provide additional experiences, and assist the student to develop scientific abstractions, truths, and laws for themselves based upon these experiences. Dewey proposed, however, that traditional science education did exactly the opposite: it started by presenting truths and facts that were outside the range of the student's experience and then presented these truths and facts as a perfected form of knowledge. These truths were symbolic, abstract, presented in the absence of their connections to everyday life, and for most students were nothing more than a strange and initially meaningless new vocabulary. This vocabulary was meaningless because words only gain meaning when connected to experiences, yet students were never assisted to gain these experiences because it was tacitly assumed that they already possessed them (or perhaps because it was never realised that they needed them).

Within traditional science education, according to Dewey, the mental is privileged over the physical and symbols are privileged over direct experiences of the things they are meant to represent. Ideally, however, an educated person will possesses a maximum of experiences and will be accustomed to reflect upon these experiences. Experience is better than theory, believed Dewey, because it is only via experience that theories gain meaning, and because reflection upon experiences can generate new ideas and theories. Moreover, since most students are never going to become scientific specialists themselves there is really no point in forcing them to memorise dry facts and results that will they will never be able to use. Rather, they should be learning something truly useful, namely, the scientific way of treating experience: the scientific method. This does not mean, however, that traditional science laboratories (labs) are the answer since within the traditional lab the problems dealt with are only those of science, not of the everyday. Moreover, the problems dealt with by students in science labs are rarely if ever genuine problems. Rather, students are attempting to replicate previous experiments and not trying to discover something truly new.

While it may seem to be a slower process to begin education with the experience of the learner, Dewey believed that by doing so the student develops a superior understanding *of* and interest *in* science. Moreover, it is a fallacy to believe that scientific knowledge can be simply imported in a ready made form. Material stated in scientific form is not somehow magically assimilable. Quite the reverse: when material is learned in this condition it remains a body of inert information. As Boulding (1956/1991) noted in this regard, “Knowledge . . . is always what somebody knows: the most perfect transcript of knowledge in writing is not knowledge if nobody knows it” (p. 240), yet somehow we imagine that if a person can verbally recite the words on a science book page from memory then they *know* that science.

According to Dewey, within traditional education students are envisaged as *theoretical spectators* who absorb scientific knowledge directly from textbooks. This ideology is, however, opposed to both human nature and science itself. Fundamentally, human experience involves both active and a passive engagement with one’s environment, both acting upon the world and then subsequently perceiving the consequences of our actions. Sometimes the initiative in activity is ours, other times it is on the part of the environment. Either way, learning consists of noting the connections between these two phases of experience. Infants learn by handling, tasting, and generally interacting with things and similarly science is itself a practical activity, involving experimentation and testing. Within the ideology of science it is empirical investigation that is held to distinguish science from other competing sources of knowledge, such as religion, and it is empirical investigation that is held responsible for science's "success and credibility" (American Physical Society, 1999).

According to Dewey, traditional education tends to make the act of learning a direct and conscious end in itself, and the activities in which students engage to facilitate learning thus become means to this end. It is quite common within schools for science students to engage in mock experiments whose ideal outcome is already known in advance, and to solve problems and puzzles that possess no personally felt significance to the student nor even any relevance in the real world. Because, according to Dewey, traditional education tends to ignore the importance of personal impulse and desire as motivating factors in learning, the process of teaching and learning within schools tends to be accidental. Those to whom the provided conditions are suitable manage to learn while everyone else manages as best they can. It is in fact undesirable for students to be made aware that they are studying or learning, however, since to the degree that they are so aware, they are not studying and learning. During daily life learning occurs as a natural result of engaging in activities aimed at accomplishing ends that one identifies with. Successful educational practice will thus mimic daily life, giving students something to do, not something to learn. This doing, moreover, will be of such a nature as to stimulate their thought and to engage them in observation and experimentation. Successful education enlists the active cooperation of the student in the development of genuine as opposed to mock educational problems and ensures that the problems being solved are the student's own or those that they can identify with.

While traditional education does suffer from some problems as far as effectiveness is concerned, education does nonetheless possess some advantages over communication. Within educational contexts the information sender has more-or-less complete control over what information is sent, and within the school classroom the educator, and through them society, is able to ensure that only culturally significant (from their point-of-view) information is transmitted. Educators are able, moreover, to exert some control over how this information is interpreted and used. It is for these reasons, therefore, that although traditional education may be far less effective at determining the conduct of students than teachers, parents, and society in general might wish (Arons, 1990), parents would still prefer that their children went to school rather than staying home and watching television all day. It is not actually the business of this thesis to make recommendations as to how the effectiveness of science *education* may be improved, but the above analysis of the ways in which science education is ineffective can help us to understand some ways in which science *communication* (in most ways a similar enterprise) is ineffective, and the improvement of science communication is very much of concern here.

## Effectiveness Within Communication

If Dewey found traditional education to be wanting, so too have many others found conventional communication (and the *popular culture* that arises from it) equally wanting. Critiques of popular culture began in Europe as early as the 16th century in the writings of Michel de Montaigne, and were continued by Blaise Pascal in the 17th and Goethe in the 18th centuries. It was, however Friedrich Nietzsche who, during the 19th century provided one of the first major philosophical critiques of popular culture (Kellner, 1999, Shusterman, 2003). Nietzsche saw culture as central to human life and proposed that its centrality lay in its effect upon the development of the individual. For Nietzsche, the popular culture enabled by modern technologies was a weak and low culture that homogenised society and cultivated conformity and passivity. It wasted the few free hours of time that people devoted to cultural appreciation and stupefied them with the trivial, superfluous, and sensational, thereby blunting their creativity and promoting their mediocrity. By contrast, a strong and healthy culture, based upon philosophy and (particularly) art, would cultivate the senses and imagination, thereby producing distinguished, creative, robust and powerful individuals.

Certainly, attitudes such as those of Nietzsche are elitist, yet the problem that lies at the root of his critique transcends individual value judgements regarding what constitutes art or ‘culture’. The tension between art and entertainment is in fact a tension between culture and commerce, a tension felt by all those whose business it is to sell art and entertainment (cf. Rosenberg & White, 1957). Within the book publishing industry, for example, this tension exists between the *cultural gatekeeper* perspective, which holds that publishers should ensure that only the *best* books (i.e. only the books that they value) get onto the shelves, and the *pragmatist* perspective, which holds that the role of the publisher is to "give the public what it wants" and not to make value judgements on behalf of them (Coser, Kadushin & Powell, 1982; Hartz & Chappell, 1997; Self, 1997; Smith, 1997).

Giving the public what it wants still requires the publisher to act as a gatekeeper (and to make value judgements), however, because some standard must be applied when making the decision regarding what the public wants. When this standard is the 'lowest-common-denominator' it would be a mistake to imagine that this gives the public what it wants. Explicit in the phrase *lowest common denominator* is the idea that what people are being given is not something that suits them as individuals but rather only something that suits the small part of their personalities that they share with many others. Because producing for a mass market tends to be more profitable than producing for a niche market, however, the tension felt by publishers is that between giving a small number of people books (or films, games, etc.) that they will deeply appreciate, and giving a larger number of people 'throwaway' novels (or blockbuster films, etc.) that they will appreciate but a little (Self, 1997; Watters & Watters, 1997).

Within educational contexts educators can send information that they and/or society consider valuable and they can ensure that this information is received by students but they cannot force students to care about it. Within communicational contexts, information senders cannot send information that they care about *and* ensure that their information is received but if it is received then receivers will care about it. It is in this respect, then, that communicational contexts are more effective than educational contexts. When people use information within communicational contexts they do so because they want to, because they are personally interested in that information, and thus there is more chance that this information will affect their conduct. Additionally, if one is able to communicate using a mass medium then potentially one can reach a great many interested people, rather than only a few disinterested students. But again, one can only access the mass media to the degree that one is able and willing to send information that people want.

It is probably necessary for the reader to be reminded at this stage that we have been dealing with one aspect of the "Level C problem", the problem that Weaver (1949) identified in his definition of communication as "How effectively does the received meaning affect conduct in the desired way?" (p. 4). This question raised two further questions, namely, "what constitutes conduct", and "desired by whom?", the latter question being the one that we have just spent so much time answering. With regard to the question of what types of behaviours constitute conduct, it is certainly the case that communication cannot be said to have occurred if the receiver of information does not change his or her behaviour in *some* way as a result. As Weaver (1949) notes:

> It may seem at first glance undesirably narrow to imply that the purpose of all communication is to influence the conduct of the receiver. But with any reasonably broad definition of conduct, it is clear that communication either affects conduct or is without any discernible and probable effect at all. (p. 5)

A reasonably broad definition of conduct (i.e. behaviour) will, however, include both internal and external behaviours, yet changes to internal behaviour do not have a discernible effect for anyone besides the person whose internal behaviour it is.  So for example, when a person reads a novel there may be no externally discernible change in his or her conduct as a result of doing so, yet internally that person now knows more and different things than before.

Within communicational contexts it does not matter that no one, besides the information receiver, can discern any conduct change.  The publishers of books and newspapers and the producers of films, television and radio programs care only (or at least, primarily) that their products should be popular, not that their users should have engaged in any particular sort of knowledge construction.  Within educational contexts, by contrast, it matters greatly that conduct change should be externally discernible since educators *are* concerned that their students should have engaged in some particular sort of knowledge construction.  It is thus the case that, while both educators and communicators are concerned with effectiveness, they each require quite different forms of evidence for this effectiveness.

## Science Communication

While the terms *science* and *communication* have been defined separately, the term *science communication* possesses meanings that are not identical to the sum of the meanings of its parts.  In seeking to define what the activity of science communication is all about, plausible places to start are the journal *Science Communication*, published by

Sage, and the textbook *Science Communication in Theory and Practice* (Stocklmayer, Gore & Bryant, 2001). According to the editor of the journal *Science Communication*:

> *Science Communication* unites international scholarly exploration of three broad but interrelated topics: Communication within research communities – Communication of scientific and technical information to the public – Science and Technology communications policy. (Rogers, 2003)

Of these three distinct science communication activities it is only the second that is discussed within Stocklmayer et al.'s (2001) textbook, and likewise within this thesis the term *Science Communication* will be understood to refer to only this second meaning. What is actually involved in the "communication of scientific and technical information to the public" requires some clarification, however. To begin with, it is necessary to define what is meant by *the public* since different observers have identified different publics. For example, a report published in Britain by the Office of Science and Technology and the Wellcome Trust (2001) identified six clusters of people in the public according to their relations to science and technology:

- The Confident Believers
- The Technophiles
- The Supporters
- The Concerned
- Not Sure
- Not for me.

Burns, O'Connor and Stocklmayer (2003) have reported a different group of six – this time overlapping – publics who are important for science communication activities:

- Scientists (in industry, academia, and government)

- Mediators (opinion makers, communicators, educators)
- Decision makers (policy makers in governmental and academic institutions)
- The General Public (various sectors and interest groups within the community, plus the above groups)
- The Attentive Public (a scientifically interested and informed sector of the public)
- The Interested Public (a scientifically interested but not necessarily well informed sector of the public).

While the concept of *the* public is thus a complex and multifaceted one, for the purposes of this thesis *the public* will be understood simply as anyone who is non-expert with regard to some particular area of scientific research that is being communicated. This being the case, it is quite possible within this definition for the public to consist of practising scientists, so long as they do not happen to be experts within the particular science being communicated.

Apart from the issue of who exactly is constituted by *the public*, the proposal that science communication is concerned with "communication of scientific and technical information *to* [my emphasis] the public" is actually a contentious one. As was explored above, communication need not be thought of as a one-way transfer of information: it can also be thought of as two-way or interactive and certainly this idea has been applied in the area of science communication. Rather than understanding the public to be deficient in knowledge and its being the role of scientists to enlighten them, an alternative (and increasingly dominant) perspective sees the public and scientists engaged in a dialogue to which each party is able to usefully contribute (House of Lords, 2000; Miller, 2000a). Any given act of science communication, therefore, may involve the transfer of information from scientists to the public, from the public to scientists, or both.

As was stated in the introduction, there are a variety of reasons why science communication is desirable for both scientists and the public. Improved dialogue between scientists and the public can serve to make the nation constituted by that public more economically competitive, can make that public more effective in its dealings with technology and the world in general, can allow that public greater power when science and technology related decisions are being made by politicians, can enable that public to enjoy science as culture, and can improve social cohesion through the sharing of a common scientific culture (summarised in Stocklmayer, Gore & Bryant, 2001a).♣ At both national and international levels the social importance of science communication has been stressed (cf. Clinton, 1994, House of Lords, 2000; UNESCO/ICSU, 1999).

Motives for the enterprise of science communication are not just social, however. Scientists, and the enterprise of science in general, stand to gain both increased funding and social authority through the development of a popular scientific culture. With respect to funding: science is an expensive enterprise and since the vast majority of scientists are not self funding they thus require some social organization to value their work enough to pay for it. A significant proportion of funding for science is derived

♣ These motivations have been challenged by some (e.g. Gregory & Miller, 1998), and their challenge is indicative of the complexity of the motivations for science communication.

from governments while the rest is sourced from corporations, venture capitalists, private universities and philanthropic foundations, and this funding will continue to be obtained only if scientists can communicate the value (and prospects) of their research to the 'publics' that constitute and support these organisations (Benson, 2001; Cohen, 1999; Fitzpatrick & Bruer, 1997; Gascoigne, 1997; Shortland & Gregory, 1991; Vaitilingam, 2001). With respect to social authority, scientists require – or at least desire – that the public should grant them status as experts (Science Media Centre, 2002), yet right now the social authority of scientists is waning. Indeed, a report in Britain by the Select Committee on Science and Technology (House of Lords, 2000, Introduction) speaks of a "crisis of trust" and states that:

> Society's relationship with science is in a critical phase. . . . On the one hand, there has never been a time when the issues involving science were more exciting, the public more interested, or the opportunities more apparent. On the other hand, public confidence in scientific advice to Government has been rocked by a series of events, culminating in the BSE fiasco; and many people are deeply uneasy about the huge opportunities presented by areas of science including biotechnology and information technology, which seem to be advancing far ahead of their awareness and assent. In turn, public unease, mistrust and occasional outright hostility are breeding a climate of deep anxiety among scientists themselves.

The relationship between trust and communication was specifically raised by Professor Colin Blakemore when he took over Britain's Medical Research Council in late 2003. In a statement titled "Scientists must communicate" he proposed that:

> Medical science is advancing so fast and has to grapple with ethical issues in fields such as genetics, stem cells and animal experimentation. It's vital that people know about the legal and ethical safeguards and trust scientists to do the work. . . . But that trust will only come if we're willing to talk openly about what we're doing and why it's important. If scientists don't do more to engage with the public about their work, people will remain confused and

> skeptical of the benefits that medical research can bring. (Blakemore, 2003)

For reasons of both social- and self-interest, therefore, it is desirable that scientists communicate their work, yet without due care the enterprise of science communication can easily be misguided or become debased. Desires on the part of governments to improve the *public's understanding of science* or *scientific literacy* have a strongly *educational* flavour (cf. Burns, O'Connor & Stocklmayer, 2003), while genuine science *communication* activities have frequently been seen as vulgarizing science (Rhees, 1979). So for example, Rennie (2001) reports that "Almost since their inception science centres have had their detractors who claim that science is of secondary consideration, sacrificed to the primary purpose of public amusement"(p. 107).♣ Similarly, Hofstadter (1998) recalls that when he was growing up "science was not sugar-coated, . . . was not combined with irrelevancies such as action-packed stories, rock music, amusing quipsters, sassy jokes, sexual innuendoes, or up-to-date teen slang", and Highfield (2000) notes that the intense competition for article space within the popular press:

> . . . encourages triumphalism, so that every gene is a milestone on that road to a cure. It nurtures scaremongering, so that every GM crop seems likely to run amok. A quote that pours cold water on a "breakthrough" is often sunk deep in a story. The pressure to be first leads to half-baked copy. The endless emphasis on the reader tempts editors to pander to prejudice and print "talking point stories" – essentially entertaining garbage.

If science journalists must resort to "triumphalism", "scaremongering", and "breakthroughs" in order to make scientific copy interesting to lay readers, though,

♣ In this regard see Kalfus, 2000, Macdonald & Alsford, 1995; Shortland, 1987 and Yardley, 1996.

perhaps this is because the written or spoken word is not adequate to the task of communicating what is intrinsically interesting about science.

# Media, Representations and Science Communication

The term *medium* signifies some physical means of both *embodying* and *moving* information through time or space, and recognition of this dual meaning can go some way towards helping us understand the wide variety of things that have been considered as media. McLuhan (1964), for example, lists amongst media forms not only the television, radio, comics, and movies, but also the telephone, the typewriter, the phonograph, and even money, the motorcar, the bicycle and the aeroplane. Perhaps because of the large number of possible media forms, the academic study of communication and the media has primarily been concerned only with mass communication and the small number of mass media (Jensen, 1998). According to DeFleur and Dennis (1996), mass communication may be conceptualised as possessing a number of core characteristics, including the professionalisation of the processes of both message authorship and of encoding the message into media, the use of specialised (mechanical/electronic) technologies to encode/transmit/decode the message, the transmission of these messages widely, rapidly, and continuously, the existence of a large and diverse audience to whom the messages are sent, and the ability of the mass communication medium to allow individual receivers to construct meanings that to some degree parallel those intended by the professional communicators. The media most commonly understood to fit these criteria are print (i.e. books, magazines, newspapers), film, and broadcasting (i.e. radio and television), however during the early 1970s a new medium emerged that has since achieved mass medium status, and this medium is the digital game. Digital games are unique amongst the mass media in that they are interactive, and it is by virtue of their interactivity that digital games may be more effective than the other mass media at communicating science. In order to understand what is special about interactivity in this regard, however, it will first be necessary to understand how the existing mass media communicate science.

## Symbolic, Iconic, and Interactive Representations

As discussed earlier, Peirce (1868, 1894) proposed that there were three basic types of representations, namely, symbols, icons, and indices, and it is the first two of these that are primarily communicated via the conventional mass media. All of the images that fill a television or cinema screen, or the pictures in a book or magazine, and many of the sounds emitted by the speakers of a television, radio, or at the cinema, are iconic representations in that they share a physical likeness with the thing they represent. By contrast, all spoken and written language is symbolic in nature. Now, symbols facilitate information construction through their association with our various stored experiences, and thus the meanings that any given symbol (such as a word) evokes within us ultimately depends upon the experiences that are associated with that particular word. If others are to correctly select words to send to us so that we will have the thoughts or experiences that they wish us to have, they must first have some idea what our existing knowledge structures are like. Usually people just assume that the receiver of their messages possesses the same knowledge structures as they do themselves, but of course this is never entirely the case and frequently it is hardly the case at all, as for example when we speak to a person who has a poor command of our language. This of course constitutes a severe problem for symbolic communication since how are we to communicate effectively if we do not know what meanings will be attributed to the words with which we are trying to communicate? In respect of this problem Weaver (1949) notes that:

> . . . this basic difficulty is, at least in the restricted field of speech communication, reduced to a tolerable size (but never completely eliminated) by 'explanations' which (a) are presumably never more than approximations to the ideas being explained, but which (b) are understandable since they are phrased in language which has previously been made reasonably clear by operational means. For example, it does not take long to make the symbol for 'yes' in any language operationally understandable. (p. 5)

To say that the meanings of the words in a language have been defined *operationally* means that they have been defined through overt, objective, and ideally social action, as is exemplified by Messaris (1994) when he notes that "children who have just learned a new word will sometimes point to a variety of objects repeating, in each case, the same question: 'Is this an X?' 'Is *this* an X?'" (p. 120). The problem of communicants possessing different meanings for the same words will thus exist to the degree that those communicants are not able to engage in similar interactions with similar objects and processes, and especially when they are not able to engage in collaborative activity with regards to those objects and processes.

This idea that words only gain their meanings through shared or collaborative experiences with an object or process has particular relevance to the topic of science communication, and this relevance becomes apparent when one considers the following three paragraphs:

> [I]f there existed a codon for formylmethionine, this would provide a mechanism for both chain termination and chain initiation. The codon in mRNA for formylmethionine is probably AUG or UU. Its presence signals the attachment of N-formylmethionine, which must be the beginning amino acid. It has a free carboxyl that can attach to the next amino acid in sequence until another punctuation codon is reached, at which point the functional peptide falls off the ribosome. (DeBusk, 1968, p. 119)

> A structure called the claustrum – situated deep to the insular region of the cortex, receives inputs from . . . and projects to . . . almost all areas of the cortex. Since, apart from its diffuse innervation from the brain stem, it receives no other input, it could well be described as a satellite of the cortex. Only the visually responsive part of the claustrum has been intensively studied, and it has been shown to be systematically connected with the striate cortex and the adjacent visual area. (Crick & Asanuma, 1986, p. 350)

> The strongest difference between SPS and RHIC collision results is the order of magnitude enhancement in strange particle yield per participant; this result is not new but has so far found little attention. The strangeness yield rise increases compared to SPS in a manner which is more spectacular than the increase in the total hadron multiplicity. (Rafelski & Letessier, 2004, p. S1)

If the reader of these sentences has never interacted in any conscious way with a codon, a claustrum, or a strange particle, then the words used to label these objects can have little substantial meaning. Because, as Weaver (1949) notes above, explanations ultimately rely upon meanings that have been operationalised, a person cannot completely understand the nature of a *strange particle* (for example) simply by reading a verbal definition of it in a textbook. Unless the terms used in that definition have themselves at some earlier time been operationalised for the reader then the explanation will be no more meaningful than was the original term. Now, unlike members of the lay public, the molecular geneticists, neurobiologists, and particle physicists of the world have had the concrete physical experiences necessary to operationalise the meanings of terms within the above sentences. Experimentation is an highly interactive and physical process that most scientists engage in at some time in their careers, and through experiments and the use of various kinds of apparatus, scientists are able to interact with the worlds that they study in a way that others never get a chance to do. Because of this difference in the experiences of scientists and laypeople, therefore, symbolic communication between scientists and laypeople tends to be ineffective.

While communication using symbolic representations can only occur effectively when the sender and the recipient of the transmitted information both possess similar knowledge structures, communication using iconic representations is not necessarily faced with the same problems. Traditional forms of iconic media (sound recordings, photographs, films) imitate the perceptual cues that people use in their interpretation of raw, unmediated reality and thus:

> Unlike the conventions of written language or, for that matter, speech, pictorial conventions for the representation of objects and events are based on information-processing skills that a viewer can be assumed to possess even in the absence of any previous experience with pictures. (Messaris, 1994, p. 4)

Iconic representations thus possess a considerable advantage over symbolic representations as means of communicating unfamiliar experience. They also possess two advantages over unmediated experience itself. First, iconic representations allow for the customisation of experience according to the needs of the end user (i.e. they can be tailored for the needs of the individual end user in ways that unmediated experience cannot be). Second, they allow the information sender to shape the experience provided so that it is in fact more informative than would be the case under conditions of natural, everyday experience (Schwan, 2002). So, for example, the makers of a nature documentary may spend many months filming and yet create from this material a television program lasting only an hour, simply because they desire to show only the most interesting images.

While iconic representations are in some ways superior to symbolic representations for communicating science to non-experts, in at least one important way they are inferior. That is, iconic representations (e.g. sounds, images) are not easily able to be used as part of analytic communication. Analysis is one of two essential functions of communication (Messaris, 1994), the other being description:

> Description entails an account of a particular series of events or of the features of a particular object or situation. Analysis differs from description in two major ways . . . First, it often deals with generalities, classes of objects, situations, or events rather than individual cases; second, and more important, rather than simply reporting events or the characteristics of objects or situations, it is concerned with establishing the conditions under which these events or characteristics can be expected to occur. (p. 22)

Verbal language contains individual terms and syntactic devices that enable great subtlety in the communication of abstract ideas, causal or contingent relationships, rules, hypothetical situations, probabilities, generalisations, and laws, and is thus an ideal medium for analytic communication. Visual images, by contrast, are tied to the concrete visual situation (Vygotsky, 1978), are best able to depict single instances of particular objects and events, and thus while they are excellent media for descriptive communication they are quite deficient as media for analytic communication. According to Messaris (1994), the only way that images could be used to facilitate analytic communication "would be for them to replicate the entire range of individual instances encompassed by the propositions expressed in the words . . . to regurgitate the entire mass of specifics encapsulated in any one of the verbal constructions" (p. 117)[♣], and this a messy way of communicating when one could more effectively use words. Because of their deficiency in this regard, therefore, iconic representations are not, on their own, useful for communicating the ideas of any intellectual disciplines other than purely descriptive ones (Messaris, 1994).

While neither symbolic nor iconic representations are ideally suited to communicating scientific ideas, there is a media form that is capable of providing its users with both quasi-unmediated experience of an object or process and the possibility of developing abstract understandings of that object or process. This media form is the *computer-based simulation*, and simulations are able to represent, not just how an object or process *appears*, but also how it *behaves*[♠]. Unlike symbolic media, simulations can provide their users with sense-based experiences of a system, and thus even small children can appreciate the form of a system when it is simulated. In addition, however, the users of simulations can construct qualitative understandings of how the simulated system functions, and thus simulations are more effective at communicating scientific models to non-experts than are either symbolic or iconic media. Of course, scientific simulations are not themselves a mass medium and only scientists can gain any value or enjoyment

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[♣] There is actually another way that pictures can communicate abstract ideas, and this is when the pictures themselves becomes abstract, as they are in comics and other abstract art. When this happens, however, the images themselves become more like symbols (McCloud, 1993) and at the same time begin to lose the unmediated quality that veridical images possess.

[♠] It would actually be correct to label interactive media as iconic in that they do mimic the form of that which they represent (i.e. its form of behaviour). Since the concepts of symbolic and iconic representations pre-date the existence of interactive media by many years, however, usage has determined that interactive media be seen as something different from and separate to iconic representations. It remains the work of media theory to rectify this problem.

from using them, yet if those simulations were made the basis for digital games then they might be appreciated by a mass audience.

Edwin Slosson, a pioneer American science communicator, proposed in 1921 that:

> . . . we can get into the papers a certain amount of scientific information by giving it a sensational form. That is good as far as it goes. I believe in it . . . But we must recognize that when we conform to the prevailing sensational demand, we are not getting over the best part of science. We are not educating in the scientific mode of thinking . . . (quoted in Rhees, 1979, Chapter II, Part II)

Newspapers and television documentaries do not "get over the best part of science" and they do not educate their users in "the scientific mode of thinking", but digital games based upon scientific simulations might do these things. Certainly, scientists engage in the practise of science using simulations, and simulations are themselves a quintessential scientific product: they are dynamic models of some aspect of reality. Taken at face value, therefore, digital games appear to be an excellent medium with which to communicate science. Is there any reason to believe, though, that it would be possible to make enjoyable science-simulation based games? After all, very few digital games are based upon scientific simulations have been made, and most of those that have been made are not enjoyable to play. Moreover, even if such games could be made enjoyable is it really certain that players would learn any science from playing them? Some substantial investigations will be required before it can be stated with any assurance that digital games are capable of making science intrinsically enjoyable, and until these investigations have been conducted there will be no compelling reason to believe that a popular scientific culture could be created using digital games.

# An Hypothesis

The hypothesis that will be tested in this thesis is that digital games based upon scientific simulations can make scientific knowledge construction intrinsically enjoyable for non-experts, and this hypothesis will be tested by comparing the attributes of scientific simulations that make them useful for scientists with the attributes of games that make them enjoyable to play.  While only a few digital games based upon scientific simulations (to be referred to henceforth as *science simulation games* or *SciSim* games) exist, a great many scientific and educational simulations and games exist, and as shown in Table 1, these simulations and games are quite similar to SciSim games.

A SciSim game is a digital *game* based upon a *scientific simulation* that has been designed to be used in *communicational* contexts by people who are *non-expert* in the science upon which that simulation is based.  In contrast: digital games in general are not based upon scientific simulations; science simulations are used by experts and are not games; educational simulations are not games and are not used within communication contexts; and educational games are not designed to be used within communicational contexts.

**TABLE 1** – The relationships between SciSim games and the other types of games and simulations investigated in this thesis.

| | Communication. | Science | Non Experts | Game | Simulation |
|---|---|---|---|---|---|
| SciSim Games | Yes | Yes | Yes | Yes | Yes |
| Digital Games | Yes | No | Yes | Yes | Yes |
| Scientific Simulations | Yes | Yes | No | No | Yes |
| Educational Simulations | No | Yes | Yes | No | Yes |
| Educational Games | No | Yes | Yes | Yes | Maybe |

While digital games have not as yet been studied with respect to their potential for science communication, there exist a large non-scholarly literature concerned with the nature of digital games in general; a large scholarly literature concerned with the nature of simulations and their ability to facilitate scientific knowledge construction in both scientists and science students; and a literature of moderate size, both scholarly and non-scholarly, concerned with the nature of educational games. If, through an analysis of these literatures, it could be shown that certain attributes of simulations and games make them effective in facilitating scientific knowledge construction, that digital games possess these attributes, and that it is these same attributes that make digital games entertaining, then it would have been shown that SciSim games can make the construction of scientific knowledge intrinsically enjoyable and can facilitate the creation of a popular scientific culture. If, however, one or more of these things could not be shown then on the basis of the present research there would be no reason for believing that scientific culture might be significantly more popular than it is now.

In order to convincingly support the *general* claim that certain attributes of simulations and games make them effective in facilitating scientific knowledge construction it would not be enough to simply cite evidence from one study, one user, or about one simulation or game. Rather, in order to support such a general claim what is needed is evidence that a large number of scientists or educators have found a particular attribute of simulations and/or games to be useful in practice. A wide variety of writings of scientists, science educators, and simulation and game researchers has thus been studied in order to uncover if indeed any attributes of simulations and/or games have been found to be generally useful. Similarly, a wide variety of writings of game designers, critics, and players has been studied in order to uncover what attributes digital games have, and what attributes make them enjoyable to play. The next four chapters of this thesis (Chapters Three through Six) provide the reader with general overviews of the nature of, creation of, and use of: digital games, scientific simulations, educational simulations, and educational games. It is then the task of Chapter Seven to reveal whether or not, on the basis of the evidence presented in the previous four chapters, SciSim games can make the construction of scientific knowledge intrinsically enjoyable.

*If one would seek good companions, he will find them among those with whom he studies Learning and calligraphy. Harmful companions to avoid will be found among those who play go, chess, and shakuhachi [the flute]. There is no shame in not knowing these latter amusements. Indeed, they are matters to be taken up only in the stead of wasting one's time completely.*

*(Hojo Nagauji (1432-1519)*
*Samurai general)*♣

CHAPTER THREE

# Digital Games

While the overt purpose of this chapter is to discover the attributes of digital games and what attributes make them enjoyable to play, its underlying purpose is simply to introduce digital games to the reader. Such an introduction is necessary because, while digital games have received academic interest as a social problem, a technological challenge, an economic force within the entertainment industry, a cultural phenomenon, and as an expansion of traditional media forms such as the narrative, until very recently they have not received attention as a media form in their own right (Bryce & Rutter, 2003; Frasca, 1999; Jenkins, 2002b; Zimmerman, 1999). There are a number of probable reasons for this. First, play is generally thought of as a childish activity and much of what children do and produce is not generally considered valuable. Also,

♣ From "The Twenty-One Precepts of Hojo Soun". In G.N. Lee (Ed.) & W.S. Wilson (Trans.), *Ideals of the Samurai: Writings of Japanese Warriors* (pp. 73-80). Santa Clarita, California: Ohara Publications Inc. 1982. Square brackets my addition.

because play is considered childish it is also considered ‘easy’ and lacking in challenge, effort or commitment on the part of the player (Rieber, 1996). A second reason for the academic neglect of games is that they are not considered serious activities (Christopher, 1999). Play is usually regarded as a useless, unserious, frivolous, timewasting, or at best inconsequential activity (Brody, 1993; Juul, 2001b; Pearce, 2002b) and within societies maintaining some form of work ethic, activity without a worthwhile end is in turn considered irrational, morally dangerous or outright evil (Lieberman, 1977). A third reason for the academic neglect of games is that they, alongside most other kinds of popular culture such as comic books, movies, popular music, and also other new media forms, are usually not considered culturally important (Aguilera & Mendiz, 2003; Smith, 1999). It always takes some time for a new art form or medium to be accepted as such by the cultural establishment, and games are still a young medium (Eskelinen, 2001; McCloud, 1993; Monaco, 2000). Whatever the actual reason for the scholarly neglect of digital games, though, the end result is the same, namely, that games require an introduction. This chapter introduces the various types of game hardware and software and discusses what makes a game a *game*, what factors determine how ‘good’ a digital game is and who plays digital games, and what factors affect their creation and distribution.

## A Note on Terminology

A number of terms used in this section possess similar, but not identical meanings. The title of this thesis refers to *digital games*, yet this section also talks about *interactive entertainment*, *video games* and *computer games*, and these latter two terms are far more familiar than is the term *digital game*. Given that Wolf and Perron (2003) have recently published *The Video Game Theory Reader* and provide a strong rationale for using this title, it might seem ill advised to use a different term. There are however some compelling reasons for preferring the term *digital game* in this context, namely that:

1. the terms *video game* and *computer game* have established meanings, as described below, and the term *digital game* encompasses both;
2. not all interactive entertainment takes the form of games (e.g. data-intensive interactive entertainment (to be described later));
3. the term *digital* has become synonymous with all things computer-related, and thus the term *digital games* will be readily understandable as referring to computer-based games.

This terminological choice is simply a matter of convenience, however, and should not be understood to signify that any doubt exists amongst game researchers regarding their collective object of study, as this is certainly not the case.

## Games and Entertainments

The class of media known as *interactive entertainment* possesses characteristics of both games and entertainments. Games and entertainments are similar in that they are both used within communicational contexts, as described in Chapter Two. In other ways, however, they are fundamentally different. Both games and entertainments are created, for example, from different basic components. The basic component of the game is a *rule* while the basic component of entertainment may be (somewhat awkwardly) termed an *event*.

Designers of any given type of art or entertainment have a range of possible events, and possible relationships amongst those events, from which they may select when designing that art or entertainment. For example, a musician has a range of notes and melodies to choose from, a chef has a range of foodstuffs and recipes to choose from, a writer has a range of characters and plots to choose from, a painter has a range of colours and patterns to choose from. While this range is explicit for designers (in the sense that they consciously select certain events from this range when they are designing) it is implicit for users. Users, that is, do not get to experience the range of choices; they only get to experience the finished product (Manovich, 1998).

When a form of entertainment is extended over time (as is the case with stories, music, and dance, but as is not the case with paintings or sculptures), the events that make it up are related by (apparent) cause and effect such that when certain earlier events occur, certain later events occur as a consequence. So for example, in the novel *Pride and Prejudice* (Austen, 1813/1956) the arrival of Mr Darcy and Mr Bingley at Meryton leads to Jane Bennet and Mr Bingley falling in love, which leads to Mr Darcy's attempt to separate them, which leads to Elizabeth Bennet refusing to marry him.

Like stories, games are also extended over time but games differ from stories in that, whereas a story is a linear chain of causes and effects, a game is a space within which many chains of cause and effect can be explored (Crawford, 1982). Expressing the same idea another way, a story is a sequence of events that are fixed, but a game is a space within which many sequences of events may be explored (Manovich, 1998). Another way of understanding the relationship between games and stories is through the concept of dimensionality:

> A cube, for instance, is a 3D object. Reducing its dimensionality yields a square (2D), a line (1D), and finally a point. Reducing the dimensionality of a film yields a still frame. Reducing the dimensionality of urban planning gives you architecture. Reducing the dimensionality of a game, by eliminating all but one of the possible trajectories through the world, yields a story. (Herz, 2001, p. 1)

Similar to the designer of entertainment, the designer of a game also selects from a range, but from a range of possible rules rather than a range of possible events (Callois, 1961). The end result of this selection process is a closed system of rules: a finite set of rules that do not develop over time, or at least, not within the context of any given instantiation (i.e. playing) of the game (Zimmerman, 1998). This is just the same as with any piece of entertainment: *Pride and Prejudice* is a finite and fixed collection of events and this collection has remained the same since the book was published.♣

The rules selected to govern a game may be abstracted versions of the rules governing some aspect of reality. For example, the moves that chess pieces can make are abstract versions of the powers of the characters (i.e. queen, rook, pawn) they represent. In the case of physical games some of the rules governing the game may be the same physical rules that govern the world more generally. For example, among the rules defining the game of tennis are $F_g = G(m_1 m_2 / r^2)$♥ (i.e. Newton's Universal Law of Gravitation) and the

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♣ At least, there is a published edition which has remained the same. But of course there have been various films, television mini-series and abridged novels that have departed from the original text.
♥ Where m1 and m2 are two masses, Fg is the gravitational force acting between the two mass, $r^2$ is the distance between the two masses and G is the universal gravitational constant.

relationship force = mass x acceleration. Tennis players cannot cheat and break these physical rules; they can only break the human prescribed rules and only when they are partially responsible for enforcing them. Digital game players are even more restricted than sports players because the computer absolutely enforces all the rules.

It is the rules of a game that define the size and dynamic nature of the game-space: they determine all of the instances of that game that can actually be played (Prensky, 2002a; Wright, 2000; Zimmerman, 1999). By determining the number and type of the different game elements (e.g. in the case of chess, these are the board, the pieces, and the two players), and also all the possible ways that the game elements can sequentially interact with or relate to each other, the rules also determine the number of different sequential selections of events, or traversals, that can occur within the game-space. The relationship between a game-space and the possible traversals through it may be understood using the metaphor of the branching structure of a tree. At the beginning of a game a certain rule-prescribed state of affairs exists (e.g. the initial positions of the chess pieces), and this initial state may be likened to the trunk of a tree in that there is only a single trunk and thus no choice about where to begin. One player then makes a choice from amongst a set of options, followed by the other player and so on for the rest of the game, and these sets of options may be likened to the branches of the tree. The more branches there are, the greater the range of choices available to the players (the more freedom of choice they have) and the larger the size of the game-space.♣

♣ This branching metaphor, and the use of the term *game-space*, suggests that a given point in a game should be thought of as a location. Another way of looking at this problem is, however, to consider the game as a complex system capable of taking on various states (Juul, 1999). That games are usefully viewed as complex systems is an idea that will be returned to frequently.

The player of a game, like the author of a story, is engaged in a creative act. He or she is in fact selecting certain events to occur from amongst a larger set of options that are the choices the game makes available. A single playing of a game (a single traversal of the game-space) is thus in fact structurally identical to a story, at least as far as any game spectator is concerned (Crawford, 1989; Frasca, 1999), and indeed audiences at a theatrical or musical performance and spectators at a sporting event actually attend for similar reasons[◆]. In both cases, that is, the onlookers hope to experience an interesting sequence of events. The difference between the two situations is that the selection of events occurs in real time in the case of a sporting event (i.e. during the playing of a game) whereas the selection occurred in some past time in the case of a musical or theatrical performance (impromptu musical and theatrical performances being exceptions to this rule).

Multiple playings of a game reveal the rules and intricacies of its game-space in a way that multiple readings of the same story never can. This is because, unlike in the case of a game, the rules that governed the story author's choices of events no longer exist to generate new stories and thus the reader of a story is stuck with the same events each time the story is read (Costikyan, 1988). If the novel *Pride and Prejudice* were a game then it would be possible to see if there was some way to make Elizabeth Bennet marry Mr Wickham, or to prevent Lydia Bennet from marrying him, and thus we could come to understand both these characters better. Since *Pride and Prejudice* is not a game,

[◆] In this context, Monaco (2000) notes, "One of the most obvious candidates for admission to the spectrum of the arts is sports" (p. 34).

however, we can only understand the characters based upon what they actually did in the story.

Not only is the basic structure of a game different from the basic structure of an entertainment (such as a novel, a painting, or a musical performance) but the players of games have qualitatively different experiences to the users of entertainments. The users of entertainments are largely passive and the actions they take rarely have much, if any, impact upon the sequence of events that make up the entertainments. Spectators at sporting events do have some impact when they cheer for their side but the reader of a book has no impact at all upon the sequence of events that take place within it. This passivity on the part of the user is generally desirable in the case of entertainments because the major selling point of conventional entertainments are their dramatically or aesthetically compelling nature. Whether we are spectators at a sporting event, the audience at a play or concert, or viewers of a film or TV program, we are presented with the work of people whose professional role it is to do 'great things' – to score impressive goals or sing beautifully or write or enact great stories. As spectators and viewers we cannot control what the performers do but this is just as well because any interference from us would only spoil their performance. When it comes to playing a game, by contrast, we are not interested in the authorship of others, we want to produce great performances and be the authors ourselves. As game players we are active and what we do determines (at least in part) how interesting a path we take through the game-space, and ultimately how our game will end.

When people play they are not just doing something, they are *trying* to do something (Dewey, 1916). Every gameworld can take on one or more states which are of significance to the players because the occurrence of these states signals the game's end, and what the players of a game try to do is to manipulate the gameworld into (or to prevent it from being manipulated into) such a state or states. In chess these states are checkmate, stalemate, or some overwhelming advantage that will cause a player to concede defeat. In tennis these states are winning the best of three or five sets. In *Space Invaders* there is only a single state signalling the end of the game, and that is when all of the player's gun turrets have been destroyed. These states that a gameworld can take on may loosely be referred to as the game's goals, though usually a game's goals are stated positively. Thus in *Space Invaders*, for example, although the player can never 'win' and always dies in the end, they may nonetheless think of their goal as to "accumulate as many points as possible". Across games as a whole there are a number of regularly used goals: collecting something, gaining territory, getting somewhere first, reaching the highest possible level of proficiency and/or efficiency, and/or being the best among or eliminating other players (Leemkuil, de Jong & Ootes, 2000; Rollings & Morris, 2000). Apart from its overarching goals, however, a game usually also has subgoals that represent minor endpoints within the game. Taking an opponent's piece may be characterised as a subgoal within chess, for example, while winning a point is subgoal in tennis.

The path that players take to reach the goal of a game is never determined wholly by their actions alone (if it were then the game would not be a game at all but would instead be a puzzle, as shall be described later on). Rather, the path the player takes is always some more-or-less complex function of their desired path, and this added complexity is the result of the actions of the opponent player and/or the nature of the gameworld itself. So for example, in the case of tennis each player attempts to hit the ball over the net and within the boundary lines in such a way that it cannot be hit back, but their efforts are actively opposed by the other player and passively opposed by the net, the locations of the boundary lines, and gravity (amongst other things). It is these added complexities that constitute the challenge of a game.

Just as the essential experience of entertainment is the appreciation of drama and aesthetics, the essential experience associated with playing a good game is one of challenge, and people play games because they enjoy being challenged (Adams, 2001c; Durkin & Aisbett, 1999; Interactive Digital Software Association [IDSA], 2001b, 2002; Inbar & Stoll, 1970; McFarlane, Sparrowhawk & Heald, 2002). Being challenged involves many things, including developing a skill, trying out solutions to problems, thinking actively, trying to understand the gameworld, and exercising control. Winning, scoring, progressing, improving one's performance and beating an opponent are also important aspects of challenge within games (Durkin & Aisbett, 1999; Mount, 2002; Rouse, 2000).

There are three major types of challenge – varying in their 'adversarialness' – that a gameplayer may face, and these are *complexity*, *competition*, and *conflict*. Challenges based upon complexity are the least adversarial and require the player to understand the complex behaviour of the gameworld. Challenges based upon conflict are the most adversarial and require the player to understand the complex behaviour of their opponent. Between complexity and conflict in adversarialness are challenges based upon competition, and these require the player to understand both the gameworld and their opponent.

A flight simulator is an example of a game whose challenge is based upon complexity.[♣] Flying a simulated aircraft is a difficult task intrinsically, not because the aircraft is attempting to thwart the player's intentions. Technically speaking, games whose challenges are based only upon complexity are not actually games at all and are instead referred to as *toys* (Crawford, 1982; Wright, 2000). There are no particular states within toys that have been designed to constitute their end: they provide no equivalent of *checkmate*. This does not mean there are necessarily no 'natural' endpoints within toys, however, because indeed there can be. The player's aircraft in a flight simulator can crash or run out of fuel, for example. If the user of a toy can discover some such natural goals then they can treat that toy like a game, and thus the distinction between a game and a toy ultimately depends upon the intentions of its user.

When playing a game whose primary challenge is one of conflict, a player wins by actively defeating the other players. In games such as tennis, football, basketball, and boxing, for example, each side attempts to win by simultaneously scoring points while preventing the other side from scoring points. It is because each side acts to thwart the

[♣] Indeed, all simulation games make use of complexity as their primary challenge.

plans of the other side that games based upon conflict are adversarial. Boxing is an excellent example of a game whose challenge is almost entirely based upon conflict since almost all of the complexity to be dealt with is generated by the opponent.

A challenge takes the form of a competition when a group of players are all attempting to accomplish the same goal and cannot directly impede each other's activity, though they may be able to do so indirectly. A familiar example of such a situation is provided by the game *Monopoly*. In this game players cannot steal each other's property or money, but by building hotels they can lay traps that other players may fall into. The challenge provided by *Monopoly* thus arises from both the intrinsic complexity of the gameworld and also from the complexity of the behaviour of the other players.

By virtue of the opposing actions initiated by other players and the complexity of the gameworld, the precise nature of the challenge faced by the player of a game changes with each action that they take. This is not true in the case of puzzles, by contrast, which is what makes them different from games. Puzzles are not active dynamic systems in their own right as are games and in the absence of the puzzle-solver no change will take place to the puzzle-system. Only the puzzle-solver makes any changes to the state of a puzzle and the changes that they make are always the changes that they sought to make. Because puzzles do not react to their users the challenge that they provide is essentially the same for all users. In a game, by contrast, each player plays a unique game and faces a unique challenge (Costikyan, 1994; Rouse, 2000). The challenge in puzzle-solving is not working out how to move in the desired direction through the puzzle-space but is rather in knowing what direction *is* the right direction through that space. From the designer's point-of-view, a puzzle is like a story in that the specifics of it must be carefully thought out in advance. The designer of a puzzle must make sure that at least one particular chain of events will lead to the solution and it is the task of the player to work out what this chain of events is.♣ Solving a puzzle is thus a task akin to reading the mind of the puzzle designer.

Returning again to the topic of games, the personal or impersonal opposition that the gameworld provides for the player may be conceptualised as an *agent*. An agent is one who initiates action (Laurel, 1993) or, more particularly, one who initiates complex action. Of course, what makes an action complex is a matter of subjective interpretation (a bouncing ball could be an agent for a small child, for example (Crawford, 2002)), but there is no need to dichotomise the issue: it is reasonable to allow that entities might be agents to some degree. The human players of a game are indisputably agents and the power of agency, "the satisfying power to take meaningful action and see the results of our decisions and choices" (Murray, 1997, p. 126), is another important pleasure of game playing.

It is because the path taken through the game-space is determined, not just by the player, but also by some other agency, that games (but not puzzles or entertainments) are interactive (Crawford, 2002). The interactivity that occurs between a player and the gameworld constitutes an example of a feedback loop: it is a cyclic flow of information

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♣ Depending upon the type of puzzle. Crossword puzzles, for example, do not require the solver to discover a particular correct temporal sequence of actions. The types of puzzles found in digital games, by contrast, often require this.

between them (Crawford, 1994a; Friedman, 2001).♣ Interactivity can exist to varying degrees and increases as the total quantity of information flowing between the interacting entities increases. In the case of game playing, interactivity increases proportionally to the increase in the total quantity of decision-making that a game player must perform (Crawford, 1992a, 2002).

## Interactive Entertainment

In the previous sub-section it was proposed that games and entertainments are based upon two different types of information and engage the user in different ways. The basic component of entertainment, it was proposed, is an event, and entertainments consist of events that have been chosen by someone skilled in producing drama and aesthetic pleasure for the (more-or-less) passive user. The basic component of a game, by contrast, is a rule, and by virtue of their rules games provide their players with the challenge of interactively selecting a sequence of events that will lead a game to or away from one it of its endpoints. In addition to these basic components, however, entertainments can possess some rules and be partially interactive while games can possess some events and partially require passivity.

One can understand how this might be so through considering the overall nature of a game such as chess. The rules of chess determine the general layout of the game board, the number of pieces, and what the player can do with these pieces in the gameworld.

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♣ The concept of interactivity resists simple definition. See Rafaeli (1988) and Jensen (1998) for in-depth discussions.

These rules do not, however, determine the particular shapes of the pieces, nor do they determine the size or decoration of the board. Similarly in almost all other games there are certain things that the rules specify, and certain other things that are left up to the player or those who construct the game apparatus, and these other – nonessential – aspects of games are of the same nature as the events that make up any piece of entertainment. So for example, the shapes of chess pieces are determined by sculptors, the decoration on a tennis racquet is determined by graphic designers and the music found in many computer games is determined by musicians.

The event component of a game can be very small or even non-existent, depending upon the game. Some chess players, for example, play whole games via the mail, and people can play football almost anywhere and using almost anything as a ball. There are some kinds of games, however, where the event component is particularly important. *Monopoly* is such a game. The particular shape and graphic design of the *Monopoly* board and its pieces, and the particular content of the game cards, all these things are important to making *Monopoly* the game that it is, even though these things are events and not rules. *Trivial Pursuit* is another game that has a particularly large event component. The major challenge in the game *Trivial Pursuit* is in answering the questions written on the game cards: there are few actual rules to the game.

Just as there are some games that possess a large event component so too are there some forms of entertainment that involve the spectator and are thus more interactive than others. For example, certain television game shows allow for audience members to telephone in and vote for contestants. To a lesser extent, attendance at a sporting event where one is able to cheer for one's team is also an interactive experience since through this involvement one can (to some slight degree) influence the outcome of the game. The existence of computer-based games that involve a large entertainment component, as well as of computer-based entertainments that involve a large interactive component, prompted the development of the term *interactive entertainment*.♣ The relative importance of rules or events in determining the experience of the user varies from one piece of interactive entertainment to another. As the relative importance of rules increases the interactive entertainment becomes more *process-intensive*, more interactive and game-like, while as the relative importance of events increases the interactive entertainment becomes more *data-intensive* and more like conventional entertainment (Crawford, 1988a, 1988b; Rollings & Morris, 2000).

It is essential to the nature of interactive entertainment that, while it possesses elements of both games and entertainments, these elements are mutually antagonistic to one another and as the influence of one increases the influence of the other declines. That this mutual antagonism of rules and events is unavoidable is made clear by considering that while the rules of a game allow the user to choose events, a piece of entertainment is made up of pre-chosen events. If the game player chooses the events then the entertainment author cannot choose them, and vice versa. Because of this unavoidable conflict over who will be the 'author' of the user's experience, interactive entertainment

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♣ Though there are other explanations. Smith (2002d) suggests that the terms *interactive fiction* and *interactive entertainment* have been coined as a way for both the digital game industry and digital game players to escape from the pubescent connotations of the terms *computer game* and *video game*.

can never provide the user with the best aspects of both the world of games and of the world of entertainments.

## Data-Intensive Interactive Entertainment

The one form of entertainment that most comes into conflict with the interactivity of games is the *narrative* (i.e. the story). Some of the earliest computer games – the *text adventures* – possessed many narrative elements, and more modern graphical adventure games still incorporate such elements. The most entertaining aspects of narratives are their dramatically compelling plots and characters, and if it were possible to freely combine such elements with the interactivity of games then a truly remarkable form of interactive entertainment would be possible (Juul, 1999), something that might be called *interactive fiction*.♣ The users of this interactive fiction would be able to participate in the ongoing action of a virtual world populated by interesting characters who could interact with each other (and the user) in dramatically interesting ways (Costikyan, 1988; Falstein, 1996; Friedman, 1994; Laurel, 1993; Littlejohn, 2001; Smith, 2002a; Whitby, 1993). As was just discussed, however, this ideal can never be realised because narratives and games are fundamentally opposed in nature and thus cannot be blended together (Adams, 1999b; Bittanti, 2001; Juul, 1998, 1999; Nelson, 1996; Pearce, 2002b).

♣ The *Choose-Your-Own-Adventure* books of the 1980s were the first popular expression of this idea.

At its most basic this conflict is a temporal one. Most digital games possess a large event component consisting of animations, music, three-dimensional environments and textured surfaces, yet none of these events must be experienced by the player as part of a sequence that prevents the player from making decisions. Game narratives, however, consist of sequences of gameworld events pre-ordained by the creator of the game, and thus the longer these sequences are the less interactive the game becomes (Talin, (n.d., a)). The practical reasons why high-quality fiction can never be combined with high levels of interactivity may be understood by considering how a narrative and interactivity are often actually combined. Earlier the action of traversing through a game-space was described using the metaphor of the branching structure of a tree. In the context of interactive fiction such a branching structure creates a *branching storyline*, a story that presents the player with certain choices, these choices leading down different sets of branches within the overall structure.

## Story Quality

The first, most obvious, problem with creating a branching storyline is that the author has to write a number of stories, and since it is easier to create one interesting story than many a branching storyline is likely to be composed of many not-so-interesting stories (Falstein, 1999; Smith, 2002a; Spector, 1999). Even if it were possible for one person to author many interesting parallel stories, however, games with branching storylines cannot allow the player to engage in significant interactivity if these stories are to remain intact. This is because when an author creates a story they create a sequence of causally connected events leading to a preordained conclusion. If the game player's character were allowed to make any choices that they liked in the gameworld, however, then it would be impossible to prevent these actions from making the preordained conclusion logically impossible. If the player is to be led towards a specific ending in a way that makes logical/causal sense, therefore, then in order to avoid problems of internal consistency their freedom (and thus interactivity) must be restricted (Adams 1999b; Smith, 2000).

Of course, one could construct a gameworld in which the story was not susceptible to interference by the player's character. One way to do this would be to make the player a detective who progressively uncovers an interesting story (as in the game *Myst*), while another way would be to create parallel or serial sets of events occurring within the gameworld, one set being susceptible to user influence and the other set being fixed (Littlejohn, 2001). The problem with either of these strategies is, however, that they diverge from the ideal of interactive fiction. That is, according to this ideal the player is able to affect the ongoing course of events in a meaningful way (Zimmerman, 1998), but this is just what they are not allowed to do using either of the above methods. Certainly, they can take actions but their actions will not be narratively meaningful (Game-Research.com, 2002). As a concrete example of the problem with both strategies consider that if a game player controlled Elizabeth Bennet in an interactive *Pride and Prejudice* then the moment they made a decision that varied from those she made in the book the entire rest of the story would no longer make sense. If Elizabeth was only allowed to do things that did not alter the rest of the events in the story (such as deciding what to do in the privacy of her own room), however, then her actions (and thus also the player's choices) would not be narratively meaningful.

Fundamentally, the combination of interactivity and narrative involves an inescapable tradeoff. On the one hand, to effectively tell a story one must limit the player's options such that the actions that they take are unable to affect the story (thus making them narratively insignificant) (Adams, 1999b; Egenfeldt-Nielsen & Smith, 2002; Mechner, 2000). By contrast, if one wishes to allow the player meaningful interactivity then story quality must be compromised. It thus becomes clear why interactivity and narratives are in fundamental opposition. The freedom to make meaningful decisions is an essential aspect of interactivity yet branching storylines create only an illusion of freedom (Spector, 1999), at one and the same time attempting to give the player the feeling that the choices they make are important while making absolutely sure that they are not (Smith, 2002a).

## Authorship

At heart the tradeoff between interactivity and narrative is a conflict over who is going to be the author (Meier, 2000; Murray, 1997). Narrative is the readers' surrender to the author whereas interactivity is the player being the author (Adams, 1999b; Bittanti, 2001). As was described earlier, the player of a game and the author of a story are both engaged in fundamentally the same activity since both have available to them an array of events to choose from and both complete their works by choosing only some, and not others, of these events. Players are not, however, trying to tell stories (Bittanti, 2001) –

they are just trying to have fun – and thus they will not necessarily choose pathways that will make for a dramatically interesting narrative. Moreover, the users of entertainment do not want to have to tell their own stories, but rather want someone skilled to tell *them* a story:

> The problem is – and it's terribly obvious really – that most successful communication involves a great deal of craftsmanship and authorship and point of view and storytelling and narrative. Every successful form, be it a novel or a feature film or a play or a comic, needs a skilled storyteller to weave together a spell in the mind of the audience, suspend their disbelief and take them on a carefully planned emotional roller coaster through the story. . . . By giving the audience control over the raw material you give them precisely what they don't want. They don't want a load of bricks, they want a finished construction, a built house. (Whitby cited in Cameron, 1995, p. 39)

The problem of conflict over authorship in games may thus be likened to the situation faced by two singers who wish to sing different songs and who have to share one microphone: one does not expect beautiful music to be made in such a situation.

## Lazy Bytes

Besides the tradeoff between story quality and interactivity, authors of branching storylines face other problems. One of these relates to the production of data content (i.e. events), including such things as background stills, animated characters, music and sound effects. While within a process-intensive game much data content is created algorithmically by the computer, in a data-intensive game this content must be produced by human beings and its creation thus involves considerable labour and expense (Joiner, 1994; Talin, (n.d., b)). Now, if the choices available to the player in a branching storyline really mattered – in the sense that once a choice was made the player could not go back at a later time and make a different choice – then much of this expensively produced content would never be displayed to the player, and would thus be wasted (Smith, 2002a; Spector, 1999). Even if players *are* allowed to explore the whole branching structure of an interactive story, however, this still does not mean that they actually *will* do so, and if they do not then, as before, a great deal of work will have effectively been wasted (Falstein, 1999). The potential non-use of data content is known as the problem of *lazy bytes* and because of the expense involved in creating this content there is great pressure on game designers to minimise the number of pathways that the player can take, and consequentially to minimise the player's freedom in the game (Egenfeldt-Nielsen & Smith, 2002; Joiner, 1994).

## Replayability

Another problem with branching storylines that affects their ability to be dramatically compelling relates to game replayability. Because a game may be played repeatedly, and because the player can follow a different path through the gameworld each time they play, there are no ultimately serious consequences to any action the player takes. If, for example, Elizabeth Bennet rejects Mr Darcy in one playing of the *Pride and Prejudice* game and ends up a maiden-aunt, she can always accept him the next time around. Because the player can explore all of the gameworld's possibilities and is not forced to accept any of them, therefore, there is no room within interactive fiction for fate or tragedy (Adams, 1999a; Crawford, 2000). Similarly, there is a lack of surprise in games. Stories can utilise surprise because the author can form expectations and then dash them, but the author of interactive fiction lacks the ability to form expectations to the degree that the player has power to do what they like (Crawford, 1982). It is precisely because of this power held by the player that it is thus impossible to make a game dramatically serious *and* to allow for narratively meaningful interactivity (Frasca, 2000).

While the possibility of the player replaying a game causes problems for drama, in fact interactive stories (and indeed data-intensive interactive entertainment in general) are much less replayable than are process-intensive interactive entertainments (Crawford, 1996b; Juul, 1999). Replayability is one of the hallmarks of a good game (Adams, 2001b; Aarseth, 2002; Herz, 2002) but a game is only replayable to the degree that there are many paths through the gameworld, and interactive fiction must have very few paths if the player's actions are to be limited to those that are dramatically interesting (Adams, 2001b), and if it is to be financially viable.

### Character

Interesting characters are an essential element of narratives yet they are difficult to incorporate within interactive fiction for a number of reasons. First, the player's character must have a tightly defined personality if this character is to be narratively interesting, yet this in turn means that the player must be prevented from acting out of character, and *this* in turn means that the player's freedom must be restricted and interactivity must be curtailed (Costikyan, 1988; Pearce, 2002c). An example of this problem, consider that:

> If Captain Ahab can choose a premature escape and settle down as a tobacconist in Nantucket, the story [of Moby Dick] ceases to work. This is especially true on a psychological level, because Ahab has been described as having a certain psychological profile. If this description is to make sense, he can only act in one way when faced with a choice. (Juul, 1999, p. 34)

A second reason that interesting characters are difficult to incorporate within interactive fiction is that the player's character must have 'amnesia' for previous events within the gameworld. To understand why this must be so, consider playing an interactive *Pride and Prejudice* as Elizabeth Bennet. Even if you have read the book there is still much you do not know about your parents, sisters, relations, and friends, and this ignorance affects how plausibly you can interact with them. In order to solve this problem of ignorance some artificial explanation for why the player's character knows nothing about what is going on must be developed, and this then limits the kinds of stories that may be told involving that character (Adams, 1999b).

A third reason why interesting characters are difficult to incorporate within interactive fiction is that it is still not possible to create realistic automated or artificial non-player characters (NPCs), and even though the problem has been worked on for a long time it is not yet near being solved (Crawford, 1982, 1995h; Nelson, 1996). Algorithms are poor at simulating realistic, let alone emotionally compelling, human behaviour and thus even the most sophisticated adventure games rely heavily on pre-scripted dialogue for character interaction (Bittanti, 2001; Joiner, 1994). To the degree, moreover, that it is possible to create a sophisticated enough artificial intelligence to support realistic and interesting NPCs then a new problem arises, namely, that such characters would behave unpredictably and thus could not be relied upon to form a consistent part of a plot (Woodcock, 2000). It is important to be clear, therefore, that the problem of how to create narratively interesting interactive entertainment is not a problem that can be solved by technology. Even with the most advanced technology imaginable, even with lifelike computer controlled characters that could understand the player via natural language there would still be a conflict over who (i.e. the storyteller or the game player and NPCs) was to be in control, and thus either interactivity or story quality (or both) must *always* lose out. While the dream of interactive fiction is to combine the best aspects of narratives (i.e. dramatically compelling events) and of games (i.e. absorbing interactivity) the reality is thus that what will actually be combined are the worst aspects of each (i.e. inferior stories and inferior interactivity).

It is important to make clear, before leaving this topic, that games *can* have excellent stories and simultaneously be great games (cf. Lewinson, 2004; Summers, 2004) so long as certain conditions are met. These conditions are that the game and story run parallel or in serial with each other and do not affect each other to any extent, and that the player is able to skip through or otherwise avoid story segments if they are not interested in them or if they have seen them before. This is not *interactive* storytelling, however, but just ordinary storytelling.♣

## Process-Intensive Interactive Entertainment

Up to this point we have seen that interactive entertainments vary in terms of how data-intensive or process-intensive they are and that data-intensive interactive entertainments take the form of somewhat-interactive stories. In contrast, process-intensive interactive entertainments are highly interactive and game-like, and thus, for the purposes of this

♣ The relationship between games and narrative continues to be a contentious issue. See Wolf & Perron (2003) for a variety of discussions.

thesis the term *digital game* will be restricted for use in referring to process-intensive interactive entertainments.

Murray (1997) has proposed that the four essential properties of digital environments are that they are procedural, participatory, spatial, and encyclopaedic. Digital environments are: procedural because their behaviours are based upon the execution of rules or algorithms; participatory because they are responsive to our input; spatial because of their power (very often used) to represent navigable space; and encyclopaedic because of the vast amount of information they contain. Says Murray (1997):

> The first two properties make up most of what we mean by the vaguely used word *interactive*; the remaining two properties help to make digital creations seem as explorable and extensive as the actual world, making up much of what we mean when we say that cyberspace is *immersive*. (p. 71)

In a similar vein, Ryan (1994) notes that it is immersiveness and interactivity that constitute the core elements of computer-based virtual reality since reality is both immersive and interactive.

It is by virtue of their *computer-facilitated* immersion and interactivity that digital games are able to provide for their players experiences that traditional games cannot provide, and it is thus these two aspects of digital games that are most important in determining how enjoyable they are to play. In addition to these two aspects, however, two further aspects (categorised as *metagame activities*) are subsidiary but nonetheless important in determining how enjoyable a game is. These four aspects are discussed in turn below.

## Immersion

> *Immersion* is a metaphorical term derived from the physical experience of being submerged in water. [We get] the same feeling from a psychologically immersive experience that we do from a plunge in the ocean or swimming pool: the sensation of being surrounded by a completely other reality, as different as water is from air, that takes over all of our attention, our whole perceptual apparatus. (Murray, 1997, p. 98)

Immersive experiences are those in which we lose our sense of normal reality and participate in a new reality, a reality that behaves according to new rules and within which we can behave in ways and can experience things that normally would be impossible. Within this new reality we can safely experiment with ways of behaving that might be dangerous or socially unacceptable, or we can simply enjoy manipulating a simulated reality (Carson, 2000; Crawford, 1982; Dede, 1995; Frauenfelder, 2001; Howland, 2001; Jenkins, 2002b; Murray & Jenkins, 1999; Poole, 2000; Rouse, 2000).

There are in fact four different types of immersion: actional, conceptual, symbolic, and sensory (Dede, 1995; Laramée, 1999b). Sensory immersion creates a world into which the player is drawn using tactile, auditory, or visual stimuli. Actional immersion involves empowering the player to initiate actions and participate in ongoing events. Conceptual immersion involves challenging the player, while symbolic immersion involves triggering powerful semantic associations (e.g. terror and horror). What makes all these types of immersion collectively possible is simulation. Process-intensive interactive entertainments (i.e. digital games) are simulations, that is, explorable models of dynamic and complex systems (Aarseth, 2001; Herz, 1997; Jenkins, 2002a; Juul, 2001a; Joiner, 1994; Kirriemuir, 2002b; Rouse, 2000; Zimmerman, 1999). When playing a really good simulation-based game players are so immersed in the game that they cease to be aware that they are interacting with a computer; rather, they are simply living in a different world governed by different rules from those that operate in the real world.

The two most important factors that affect how immersive a game is are its *look* and its *feel*. Look corresponds to the sensory aspects of the player's experience while feel corresponds with interactivity, i.e. with the power to act freely, to make choices, and to have those choices affect the environment (Svanœs, 1999). Look and feel reinforce each other since the more realistic and appealing an environment looks the more the player wishes to manipulate it, while the more an environment responds to manipulation the stronger will be the player's involvement with it and the more persuasive will be the illusion of being within that environment (Laurel, 1993; Murray & Jenkins, 1999).

A game will *look* real to the extent that its graphics, colour, animation and sound effects are of high quality (Crawford, 1982). The quality of the look of a game is partly determined by technology and thus the look of games has continually improved since their inception. Look is, however, also determined by the artists and graphic designers who work on a game project and thus by the time and money game producers are willing to spend.

A game will *feel* real to the degree that the various systems that make it up are realistically modelled (Garneau, 2001). As an example of realistic modelling, consider this advertising description of a car rally game:

> The development team used its advanced DYNE vehicle dynamics engine which allows each part of a car to be treated as a separate object, complete with its individual physical properties. In other words, rather than displaying the bonnet, bumpers, doors and every other vehicle component as drawn textures, the game engine renders these as actual objects. Hit enough objects on your travels and the joints between these panels become increasingly loose, swinging and flapping until eventually – assuming enough damage has been taken – they detach themselves from the main car frame. In addition, the system ensures that each area of impact crumples in relation to the forces exerted in that area and any dirt and mud that is sprayed onto the bodywork marks it in an exceptionally realistic manner. Essentially, you never end up with the same car at the end of a race – every dent, every broken part is a result of your driving decisions. (Activision, 2002)

Model realism ultimately boils down to model complexity: that is, the more complex the systems are that make up a game, the more realistic the game will seem, and this is because the reality that humans experience in daily life is made up of numerous interacting complex systems.

## Interactivity (Gameplay)

A game's feel, its interactivity, is also known as its *gameplay*, and gameplay comprises both how the player acts upon the gameworld (what choices they can make) and how the gameworld reacts (how these choices affect the gameworld) (Crawford, 1994a; Rouse, 2000). The kinds of choices that a player can make are determined by the kinds of systems that the game is based upon. If the game is based primarily upon a spatial system then the player is able to make choices relating to the disposition of objects in space. Similarly, if the system is an economic one (such as is the board game *Monopoly*) then the player is able to make choices relating to economic entities, or again, if the game is a political one (such as is the board game *Diplomacy*), the player is able to make choices relating to political relationships. Regardless of the specific nature of the systems upon which a game is based, the most important thing is that these systems be complex.

The importance to good gameplay of basing a game upon complex systems may be demonstrated by comparing games based upon complex systems with those based upon *anticipatory systems* (Rouse, 2000). As one moves from the process-intensive to the data-intensive end of the interactive entertainment spectrum, games are decreasingly based upon complex systems and increasingly based upon anticipatory systems. Whereas complex systems define a rich environment wherein many unexpected events can take place, anticipatory systems are those in which the only events that can occur and the only actions that the player can take are those that have previously been thought of by the game designer.

The challenge that games based upon anticipatory systems provide is basically one of puzzle-solving. Since puzzles rarely have more than one solution the gameplay provided by anticipatory systems involves trying to guess the right answer or make the right choice (Smith, 2002a). It is much more interesting from a gameplay point-of-view, however, if the problems offered by a game are susceptible to multiple solutions (Garneau, 2001; Nelson, 1996; Squire, 2001a). Games based upon complex systems enable problem situations capable of multiple solutions, and they can do this because they exhibit emergent behaviours (Nelson, 1996; Rouse, 2000; Wright, 2000), Emergent behaviours are features of a game that emerge via the interaction of its rules and that cannot be simply inferred from its rules (Rollings & Morris, 2000; Talin, (n.d., a)). The rules that define a game can be quite simple yet lead to great complexity. The game *go*, for example, has simpler rules than does chess but is mathematically much more complex (Zimmerman, 1999). When a game designer creates a game based upon complex systems, rather than anticipating what the player will do, they create a system in which solutions to problems can be developed that even *they* had not envisioned (Herz, 2002; Rollings & Morris, 2000; Rouse, 2000). Generally speaking, the more complex the systems that make up a game are the larger the game-space will be and the more ways there will be to solve game problems (Wright, 2000).

Earlier the metaphor of the branching structure of a tree was used to describe the player's passage through the gameworld. Games based upon complex systems will tend, however, to provide the player with choices that are not discrete, like the branches of a tree, but that are rather continuous, as is the space within a volume. A typical flight simulator, for example, does not limit the player to making discrete choices concerning where they travel in the gameworld (as does the game of chess, for example). Rather, in a flight simulator the player can travel wherever he or she desires. Thus, in contrast with games based upon anticipatory systems that present the player with a small number of choices, games based upon complex systems present the player with a large, effectively infinite number of choices (Joiner, 1994).

Because of the large game-space that they provide, games based upon complex systems enable exploration and discovery. This exploration and discovery can be of physical spaces (Crawford, 1982, 1991, 1993, 1996b; Jenkins 2002; Jenkins & Squire, 2002), of the dynamic nature of the simulated world and the properties of its environment (Garneau, 2001; Rouse, 2000; Spector, 1999; Wright, 2000), and/or of how to do things within this environment (Clarke-Wilson, 1998). Also because of the large game-spaces that they provide, games based upon complex systems allow players to experience something new each time they play, and thus such games are highly replayable (Adams, 2001c; Rouse, 2000). By contrast, the game-spaces provided by games based upon anticipatory systems are comparatively small and provide much less replayability, and this is because the only events that can occur within an anticipatory system are those anticipated by the designer.

Whilst the player of an anticipatory system-based game engages mostly in guesswork, the player of a game based upon complex systems must make *interesting decisions* and then explore the outcomes of those decisions (Costikyan, 1988; Falstein, 1996; Jenkins & Squire, 2002; Meier, 2000; Shelley, 2001). Interesting decisions involve the comparison of many options where each option has both advantages and disadvantages and both short term (i.e. tactical) and long term (i.e. strategic) components. Interesting decisions are those that are not so complex that they necessitate choosing at random or through trial and error, but are not trivially easy either, and whose effectiveness improves as one acquires a deeper understanding of the problem situation (Crawford, 1995a; Hopson, 2002; Meier, 2000; Rollings & Morris, 2000; Rouse, 2000).

Apart from presenting the player with interesting decisions to make, games based upon complex systems also allow for the player to experiment with and develop varied and unique solutions to game problems, to adopt a personalised approach to problem solving, and thus to be creative. This is particularly the case with games whose major challenge is complexity (i.e. with software toys) since when there are no enforced goals players can choose their own goals and so play the game in many different ways (Edge, 2002c; Jenkins & Squire, 2002; Logg, 2000; Rouse, 2000; Wright, 2000). In addition, when games are based upon complex systems that are also scientifically or historically accurate they allow players to use their existing knowledge and expertise when playing (which is something that players usually enjoy (Meier, 2000; Nelson, 1996; Rouse, 2000)), they allow players to be instantly familiar with some of the rules (Rouse, 2000), and they are interesting to play simply *because* they are realistic, because the ability to manipulate a realistic world that is not actually real is absorbing (Frauenfelder, 2001; Neverclear, 2002).

## Disadvantages with Complex Systems

Despite all of their advantages as the bases for games there are some problems associated both with complex systems in general and realistic systems in particular that must be dealt with if a game is to be successful. One such problem relates to game balance. A game is balanced when all game elements come into play about as often as each other and when players are unable to devise any strategies or methods of problem solving that always work (Rouse, 2000). Balance is important because unnecessary game elements make a game harder to understand without making it more enjoyable to play. Now, as the number of game elements and the complexity of their interactions increase it becomes increasingly difficult to determine if each game element is in fact performing an important function, and thus creating balanced gameplay in a game based upon complex systems is both a difficult and time-consuming enterprise (Crawford, 1982, 1995f; Joiner, 1994; Meretzky, 2000).

Another problem that must be dealt with when designing games based upon complex systems relates to challenge. Ideally, a game will always present its players with a challenge that is neither too difficult nor too simple regardless of whether they are beginners or experts (British Educational Communications and Technology Agency [BECTA], 2001; Burns & Gentry, 1998; Crawford, 1982), however, when game systems become complex it can be hard for a player to know why the game system is behaving the way it is (and thus what gameworld behaviours they can take credit for) (Wright, 2000) and it can also be hard to prevent the game from falling into unwinable states (cf. Bos, 2001; Leemkuil, de Jong & Ootes, 2000). Well designed games introduce complexity slowly in order to suit the needs of beginners (and thus help them avoid totally losing control), but at the same time such games are able to provide enough complexity to challenge experts (Crawford, 1993, 1994d; Jenkins, 2002b; Rouse, 2000; Shelley, 2001).

A further problem to be dealt with when designing games based upon complex systems relates to learning. The players of any game must engage in two different kinds of learning. The first of these is learning how to play the game, and because this type of learning occurs before the game can be played it is not enjoyable. The second kind is learning how to win the game, and because this type of learning occurs while the game is being played it is enjoyable. As an example of these two types of learning consider chess, wherein learning how to play the game primarily involves learning the movements that each of the pieces is allowed to make, while learning how to win the game involves learning how to combine such movements to cause the opponent's checkmate while preventing one's own. Now, because learning how to play a game is not intrinsically enjoyable most players of digital games are not willing to spend a long time engaged in this type of learning and will frequently not even study a game's instructions before playing (cf. Jackson, 1997; Rieber, Davis, Matzko, & Grant, 2001). The games that tend to be most successful are thus those "that anyone could walk up to off the street and play" (Howland, 2001, p. 6), games that a player might be actively engaged in within 15 minutes of first coming into contact with them (Shelley, 2001). The more complex the systems upon which a game is based, however, the more likely it is that numerous controls will be necessary to manage those systems (Crawford, 1982) and the longer it will take a new player to learn how to use those controls. This problem of control complexity is not an insurmountable one though, and *SimCity* is a game that is held to have dealt with it well:

> In the early stages of SimCity, players can ignore all but a few aspects of the simulation, and their city will still grow. But progressively, as their city gets larger, players must learn to manage tax rates, property values, crime, pollution, mass transit, waste removal, and other factors. None of these factors must be dealt with at a particular time, but each must be taken on in some fashion for a city to continue growth. This is a very clever and natural way to introduce complexity. (Bos, 2001)

A final problem with games based upon complexity relates to goals. It is important for a player to have clear goals (Crawford, 1982; Jenkins & Squire, 2002; Meier, 2000; Rouse, 2000), yet as a gameworld becomes more complex it becomes increasingly less clear what the problems are and why and how they should be solved. Now, the ability to choose their own goals can provide players with a sense of freedom, and such freedom can be pleasant. It can also, however, quickly become tedious if all the player does is randomly explore the gameworld, while conversely such exploration can become even more interesting when it occurs in pursuit of some goal (Duvall, 2001; Falstein, 1996). The challenge for game designers is thus to provide players with clear goals *and* to ensure that such goals are always able to be accomplished.

## Disadvantages with Realism

Just as complex systems in general have some disadvantages as the bases for games, so also do realistic complex systems. The problem of goals, for example, becomes particularly acute with simulation games that attempt to be realistic. Goals are essential in order for there to be a challenge yet a truly realistic simulation may not be able to provide the player with any goals. As an example of this problem consider a simulation of a solar system. This simulation might allow the user to change planetary masses and orbital characteristics, yet what challenge can it offer them? If a challenge were artificially added to such a simulation (such as by turning the planets into space-craft) then this would lower the level of realism (cf. Prensky, 2001).

There is in fact a constantly felt tension within digital game design between realism and fun (Adams, 2000; Crawford, 2000):

> In general our rule is if you come to a conflict between fun and history, you go with the fun. Our decisions are made almost exclusively to the benefit, hopefully, of the gameplay as opposed to the historical accuracy. (Meier, 2000, p. 36)

> I was never concerned with education until the game was fun. Any educational value a game might have is totally wasted if people won't play it. . . . So I really think the fun has to come first. (Wright, 2000, p. 468)

One reason for the tension between realism and fun is that reality can be boring. As Frasca (2001) puts it, game players "don't want to have to take out the virtual garbage", and thus well designed games allow players to enjoy the fun aspects of reality while sparing them from repetitive and boring (but realistic) activities (Crawford, 1982; Meier, 2000; Rouse, 2000). Reality can, however, also be inconvenient:

> "Everybody was looking forward to *Trespasser* because of its advanced physics engine", recalls Will Wright. "but when the game came out, it was just horrible. The physical constraints overwhelmed everything else. Every time you'd walk through a door with a gun, it would catch the doorjamb and fall out of your hand." (Frauenfelder, 2001)

Not only can reality be boring, but fantasy can be fun. Games often tell interesting but unrealistic stories (Rouse, 2000) and game designers often deliberately sacrifice realism to accomplish some other purpose. They may, for example, display gameworld actions in ways that make them more legible and intense than their real world counterparts, in ways that make the player feel that they are superhuman, or in ways that focus the player's attention upon particular things that the designer considers to be important (Crawford, 1982; Jenkins 2002).

Another reason why realism may need to be sacrificed is to ensure that a game is always a challenge and not either boringly easy or impossibly hard. Nelson (1996) has proposed a “Bill of Player’s Rights” for adventure games and this document is instructive regarding the relationship between difficulty and realism. Some rights that Nelson accords the player are all about keeping the gameworld real. Says Nelson, game players should:

- be able to play the entire game without doing anything illogical.
- not to need to do unlikely things.
- be able to understand a problem once it is solved.
- have a good reason why something is impossible.

All of these rights require that the world be to some degree realistic. Other rights that Nelson accords players are about keeping the game’s challenge manageable, yet these rights involve an abandonment of realism. Says Nelson, game players should:

- not be killed without warning.
- not be given horribly unclear hints.
- be able to win without the experience of past lives.
- be able to win without knowledge of future events.
- not be able to get stuck or absolutely unable to proceed.
- not have to depend much on luck.

While these rights are all desirable in the context of a game, none of them are accorded us in real life and creating a game which protects these rights will thus require realism to be abandoned to a certain extent.

Another problem with game realism is that it can lead players to develop high (and inaccurate) expectations about what should be possible in the gameworld (Jenkins &

Squire, 2002; Rouse, 2000). It is particularly important that a gameworld behave in a consistent and logical fashion (Crawford, 1990, 1994d, 2002; Mechner, 2000; Nelson, 1996; Rouse, 2000) since when some aspects of the real world are modelled players come to expect that other aspects will be modelled too. It is usually the case, however, that much greater realism may be created in some areas of a game than in others (e.g. accurate race-cars but inaccurate race-car drivers) and thus a conflict over how much realism is desirable constantly arises for game designers. This conflict is exacerbated, moreover, by the fact that a player's internal perception of how reality is may itself not be realistic (Falstein, 1996). So for example, in reality race-cars are very difficult to drive yet if the race-cars in a game are very difficult to drive players will be upset.

The game *Mario 64* is an example of a game that has handled the relationship between consistency and realism well. Church (1999) notes that:

> Players [of *Mario 64*] rarely feel cheated, or like they wanted to try something the game didn't support. By offering a very limited set of actions, but supporting them completely, the world is made real for players. No one who plays Mario complains that they want to hollow out a cave and make a fire and cook fish, but cannot. The world is very simple and consistent. If something exists in the world, you can use it.

*Mario 64* can achieve this level of consistency, in part, because it is not a realistic game. Mario does not look like a human being and the world he roams around in does not look like the real world. In many first-person shooter and adventure games, however, the game designers have striven to make the gameworld look highly realistic, and in such worlds players may well want to hollow out caves and cook fish and yet be unable to do so.

## A Role for Data in Games

While so far a strong case has been made for the superiority of process-intensive over data-intensive games, it is nonetheless the case that data (i.e. events) do play an important role in many games. One form of data that is very important to making a good game is, as was noted earlier, rich visual scenery and effects. So for example, the game *Street Fighter* offers:

> . . . players a global array of possible spaces where the individual competitions can occur: a Brazilian dock, an Indian temple, a Chinese street market, a Soviet factory, a Las Vegas show palace. In the Indian sequence, elephants sway their trunks in the background. Water drips from the ceiling into a Japanese reflecting pool. In Spain, flamenco dancers strut and crowds cheer as the combatants struggle for dominance. All of these details constitute a form of visual excess ('eye candy', as computer enthusiasts call it), a conspicuous consumption of space. Such spectacular visions are difficult to program, unnecessary to the competition, yet seem central to the game's marketing success. (Fuller & Jenkins, 1995)

Narrative elements too can be important to making a good game, providing the player with a goal that they hope to accomplish, some reason for trying to accomplish it, and some idea how to accomplish it (Adams, 2002; Howland, 2001; Juul, 2001a; Logg, 2000; Ryan, 2001). When a game is very simple its need for a story is correspondingly slight. One of the traits of classic arcade games was their ability to do without any significant story elements, and many contemporary driving, fighting, and shooting games are equally able to do without them (Bittanti, 2001; Rouse, 2000). Such stories as these types of games do have are notable for their homogeneity. Often the action of the game is set in a dystopian future-gone-bad in which a battle between good and evil rages whose outcome will determine the fate of humankind (Adams, 2001a; Crawford, 1982;

Edge, 2002a; Herz, 1997; Gailey, 1993). As an example of such a storyline consider the following from the shoot-em-up game *Deimos Rising*:

> Using alien technologies, a military force has swept to power on Mars. This totalitarian regime must be stopped and its robodroid armies destroyed. You are an elite pilot in charge of a *VacFighter*, an experimental craft equipped with both air-to-air and air-to-ground weapons. To successfully complete your mission you will need to master your fighter and its weapons. New weapons, bonuses and surprises will be available as you progress across the Martian battlefields! (Swoop Software, 2002)

Of course, such impoverished storylines, clichéd reasons for action, and general emotional sterility are not to everyone's taste, and their widespread prevalence within the world of digital games undoubtedly serves to keep many people from playing games (Adams, 2002; Crawford, 2000; Rouse, 2000). The solution to this problem is not, however, to be found in creating *interactive* fiction, but just in creating games with non-interactive but otherwise dramatically compelling storylines. Drama and mood can also be added to digital games in indirect ways, such as through the setting of the gameworld and the behaviour of the non-player-characters, rather than in ways that disrupt a game's interactivity (Carson, 2000; Rouse, 2000).

## Metagame Activities

The term *metagame* refers to those enjoyable activities that are connected with a game but that do not involve gameplaying itself (Laramée, 2001). Within the world of interactive entertainment there are two main kinds of metagame activities: those involving creativity and those involving social interaction,

## Creativity

In the early days of digital games game-software was written in *assembler*, a low-level programming language that is comparatively difficult to learn and use. The process of game creation changed, however, as game software increased in size and complexity and as the speed and memory capacity of computers increased. Now, game designers spend much of their time writing software tools known as *middleware*, and it is these middleware tools that are used to actually construct a game (Crawford, 1995c). Middleware tools include *level builders* (that enable the creation of game environments), character building kits (that enable the creation of game characters), and also scripting languages that enable, for example, the instruction of a game's artificial intelligence (Herz, 2002; Pearce, 2002a; Rouse, 2000; Woodcock, 2000).

It is becoming an increasingly common practice for game development companies to make their middleware tools available to game players along with the game software itself (Woodcock, 2000) and using these tools players are able to create both modifications to the game (known as *mods*), and also to create animated movies of events taking place in the gameworld (known as *machinima*) (Bittanti, 2001). Once created, these mods and machinima are then uploaded onto the web to be circulated amongst interest groups (Herz, 2002; Rouse, 2000). Far from disliking this form of activity (which might in the conventional entertainment industries be seen as a form of plagiarism), the game industry embraces and rewards it for a variety of reasons. First, providing players with these tools can increase the popularity of a game and can keep interest in the game alive for longer (Garneau, 2001; Pearce, 2002a; Rouse, 2000).

Second, the unpaid efforts of mod-makers can evolve and improve a game and thus be used by the original game developers for inspiration (Garneau, 2001; Herz, 2002). Third and finally, making these tools freely available allows enthusiastic individuals to train themselves to be game designers (which is useful for the industry), and also allows small and independent game companies to enter the marketplace (Jenkins 2002; Squire, 2001a).

## Social Interaction

Historically, gameplaying has been an inherently social activity yet with the advent of computer games gameplayers began to be perceived as social recluses (Costikyan, 1999; Edge, 2002d; Rouse, 2000). This change in image occurred because, up until recently, multiplayer digital games required all players to be located in the same room and using the same computer or console, yet individual computer monitors and television screens are not large enough to properly display the actions of more than a couple of game characters at a time. With the advent of the internet and online gaming technology, however, multiplayer gaming has become much easier and more rewarding (Berry, 1997; Meier, 2000). In fact, a multiplayer component is now one of the most important factors in a game's success (Zimmerman, 1999).

Socialisation around games is an important motivation for play (IDSA, 2001b, 2002), and when games include a multiplayer component they allow players to socialise in various ways: to meet others and talk about the game, to share game experiences, to play with their friends, and to cooperate with each other as part of a team (Carson, 2000;

Costikyan, 1999, 1999a; Smith, 2002c). Moreover, online gaming allows players to find and to play with others of their level of skill, and thus multi-player games tend to be where competition is at its fiercest (Garneau, 2001). In line with these benefits, the percentage of the most frequent game players playing online in the U.S. has been increasing steadily, from 18% in 1999 to 31% in 2002 to 37% in 2003 (IDSA, 2003).

While the ability to enable interpersonal communication may be the major attraction of online systems (Monaco, 2000; Odlyzko, 2001), the future of interactive entertainment is not entirely online. This is because there are certain unavoidable problems that online gaming will always have, and that make single-player gaming comparatively attractive. Some of these problems are technical (such as time lag in signalling between computers causing unpredictable behaviour in games), while others relate to human behaviour (e.g. cheating, difficulties in organising team play, differences in player quality and behaviour) (Crawford, 1995d; Game-Research.com, 2002). Moreover, single player games still have their place in the gaming world (Falstein, 1998b; Squire, 2001a). Prior to the development of the digital game there were very few games that people could play by themselves and the ability of digital games to allow this option has always constituted part of their appeal. Also, unlike multiplayer games, single player games are structured to provide an enjoyable experience for just one person and are therefore desirable for people who wish to play games without having to deal with other people (Berry, 1997; Rouse, 2000).

# Interactive Entertainment Artefacts

Interactive entertainments are, in common with other forms of electronic media, actually bipartite in nature. Should one wish to use a piece of interactive entertainment, that is, one will need both game hardware and game software. This subsection will consider each of these in turn.

## Hardware

Each of the forms of mass media we are familiar with in the modern world is based upon some kind of technology and could not exist prior to the development of that technology. The technologies involved with the electronic media follow a common pattern in that they transform information input in one form (e.g. the electromagnetic radiation of a television broadcast) into information outputs taking a different form more useful to humans (e.g. pictures and sound). What makes interactive entertainment media different from conventional media in this regard is that interactive entertainment media use computers to continuously take inputs from both a physical source (such as a CD-ROM) and also from a human user, and then create outputs that are a complex combination of both. During the last 20 or so years of the existence of commercial interactive entertainments four main types of computer hardware have been used to carry out this task. These types of hardware are best known as arcade (or coin-operated) machines, personal computers, video game consoles and handheld computers, and each type of hardware is frequently associated with a particular style of digital game.

### Arcade Machines

Arcade machines are found primarily in games arcades in shopping centres. They are coin operated, and because the owners of the arcade and producers of the machines make more (or lose less) money when each playing of a game lasts for a short time, arcade games must be easy to learn and yet difficult enough to kill most players off quickly (Logg, 2000). Arcade games thus tend to present their players with constant rapid real-time choices, they require good hand/eye coordination, and they lack more than the most basic of story settings (Falstein, 1998b; Rouse, 2000). Since games of this variety are now created for all hardware types it is more accurate to call the games played specifically on arcade machines *coin-op* games. One of the major selling points of coin-op games, at a time when many people possess home computers and/or video game consoles, is that coin-op games often possess specialised input devices (e.g. guns for shooting games, pressure plates for dancing games) and output devices (e.g. force feedback seats and controllers, large video displays) (Logg, 2000). These devices are able to both heighten the immersiveness of the games and also enable the user to engage in activities (such as dancing) that home computers and consoles are unable to facilitate.

### Personal Computers

Personal computers (PCs) are the most expensive games platforms used at home (arcade machines are the most expensive overall), but of course PCs are not just games platforms and can be used for many purposes. It is the versatility of PCs that make them in some ways the best games platforms, and in some ways the worst. On the positive side, because all new PCs are connectable to the internet they can be used to play web-based games, and these games are often free to play, do not need to be installed, and do not require users to be technically competent (Estanislao, Mills & Welch, 2002). Also, because all PCs possess a keyboard and mouse they may readily be used to play games that require complex interaction, such as simulation and strategy games. On the negative side, the large variety of different video, sound, and network cards, not to mention operating system variants, from which any given PC may be constructed can make the process of installing and running a computer game very difficult.

### Video Game Consoles

Video game consoles (e.g. *Atari 2600, Sega Saturn, Sony Playstation/2, Nintendo Game Cube, Microsoft X-Box*) can be viewed as fixed specification PCs, usually running a simplified operating system that the end user generally does not have to interact with. Compared to the PC, consoles are more stable (they malfunction less often), are more reliable (because they are designed to a fixed specification), and are less complex to use (Kirriemuir, 2002b). While new PCs are constantly released with the latest hardware and at a roughly constant price, the prices of consoles reduce as they age, often in jumps to coincide with the launch of rival consoles (Kirriemuir, 2002a).

Games are not installed on consoles, as they are on a PC, but rather are loaded into memory from a cartridge or CD-ROM. Since games are designed specifically for a given console and because consoles possess a simple operating system, new games can be played quickly and easily by people not familiar with computers. Consoles use a television set as their primary output device and thus tend to be used in the context of the lounge room or bedroom, unlike PCs which tend to be located in either a work or home office environment. Some consoles are now connectable to the internet, and while at the time of writing most networked gaming takes place using personal computers, this may change.

It costs more money to develop games for consoles than PCs since in order to understand the design of the console hardware one needs a development kit and these kits are available (at a considerable price) only to some developers (Kirriemuir, 2002b). By contrast, information regarding the hardware and software that PCs run is readily and inexpensively available and thus the PC is a more open (and thus usually more innovative) games platform (Havok, 2002). It is potentially the most profitable strategy, however, for a game design company to release its game on both consoles of various types and also PCs (Stout, 2002), and at the time of writing the PC and console markets are converging (Spector, 1999).

Video and computer games differ from coin-op games in that there is no necessity to limit the time that players use the game and the games played on these platforms can thus require greater cognitive effort in puzzle and problem solving and not simply good hand/eye coordination (Logg, 2000). There are, however, differences in the kinds of genre that are popular on PCs and on consoles. Sports and action games are the most popular video games while the most popular genres of PC games are strategy and children's games (IDSA, 2001b, 2002). Video games are much more popular than computer games in the market place, in recent years selling approximately two to three times as well in the U.S. (Figure 3).

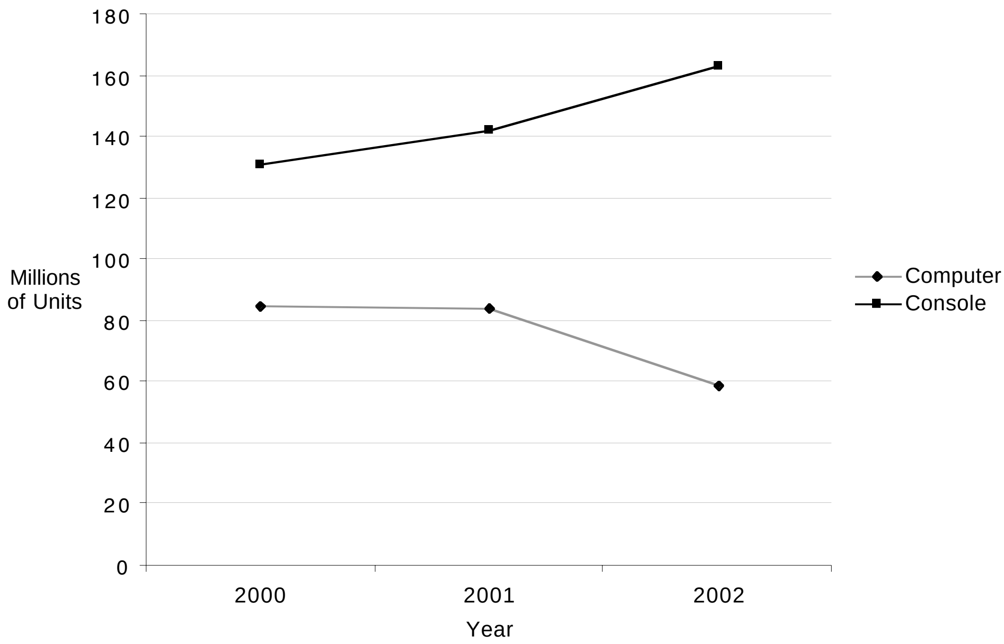


**FIGURE 3** – Comparison of sales of computer and video games. (Source, IDSA, 2002; 2003).

## Handheld Computers

Just as there are dedicated games computers (consoles) as well as general purpose home computers (PCs), so too there are dedicated handheld games computers (such as the *Nintendo GameBoy*) as well as general purpose handheld computers (such as *Palms* and mobile phones). Handheld computers have smaller input and output devices, slower CPUs and less RAM than their larger brethren, and thus the games that may be played on them tend to be simpler, arcade style games. In fact, many old arcade games are seeing new life via these handhelds.

## Software

The *genre* provides the conventional way to classify interactive entertainment software. It enables game designers and players to make sense of the variety of interactive entertainments and thus allows these entertainments to be more easily created, consumed, and appreciated (Bittanti, 2001). Little academic work has been carried out regarding game genres and thus popular genre categories originate mostly from game journalism (Järvinen, 2002).

**TABLE 2** – Lists of game genres showing commonalities and differences.

| Crawford, 1982 | Herz, 1997 | Rollings & Morris, 2000 | BECTA, 2000 |
|---|---|---|---|
| Commonalities | | | |
| Skill and action | Action | Action | Action/adventure |
| Strategy | Strategy. | Strategy | Real-time strategy |
| Adventure | Adventure | Adventure | |
| | Simulation | Simulation | Simulation |
| Role-playing | Role-playing | | Role-playing |
| Educational and children's | | Educational | |
| | Fighting | | Fighting |
| | Puzzle | Puzzle | |
| Sports | Sports | | |
| Race | | | Racing |
| Differences | | | |
| Maze | | Toys | First-person-shooter |
| Paddle | | | Management |
| Combat | | | Platform |
| Wargames | | | God-games |
| Games of chance | | | |
| Interpersonal games | | | |

Table 2 shows a group of lists of game genres created by various game researchers. Lists of genres can grow even longer than these. Wolf (2002), for example, has proposed a list of 42 different genres. One readily apparent feature of the genre lists in

Table 2 is their somewhat arbitrary nature. A racing game could, for example, just as easily fit within the genre *sports* as be provided with its own genre, and similarly the genre *first-person-shooter* could fit within the genre *action/adventure*. There have been attempts at creating theoretically-based taxonomies of interactive entertainment genres. Below are shown two such taxonomies. The first, by Talin (1994) and shown in Figure 4, sees the various forms of interactive entertainment as being mixtures of storytelling and interactivity and uses various popular titles as examples.

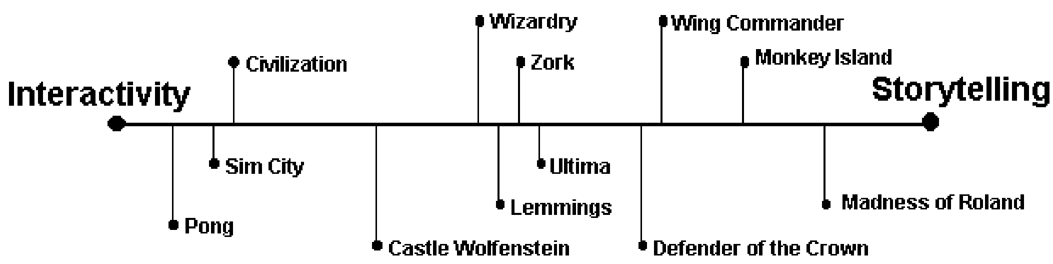


**FIGURE 4** – Interactive entertainment taxonomy developed by Talin (1994).

The second taxonomy, proposed by Crawford (1991b) and shown in Figure 5, proposes that interactive entertainment (or *intertainment*) consists of interactive stories and playthings. Toys are playthings without defined goals while challenges are playthings with clearly defined goals. Puzzles are challenges without purposeful opponents while conflicts have such opponents. Competitions are conflicts where the opponents can't directly impede each other while games are conflicts where they can.

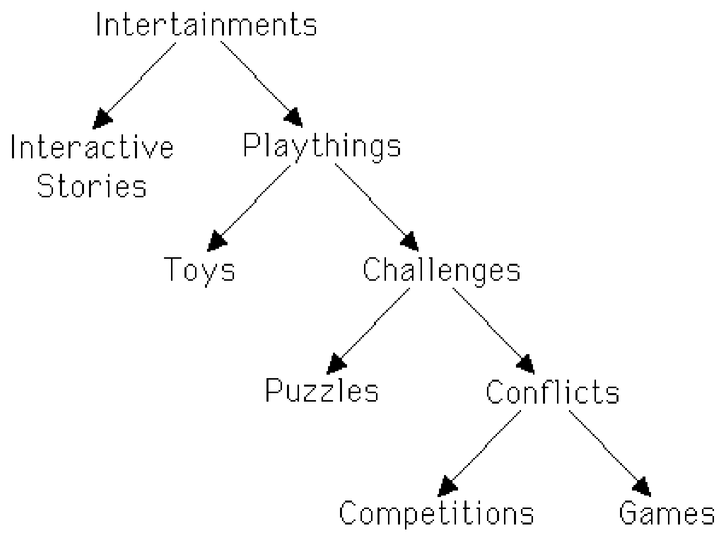


**FIGURE 5** – Interactive entertainment taxonomy developed by Crawford (1991b).

The distinction made earlier between data-intensive and process-intensive interactive entertainments is reflected in the structures of both the Talin (1994) and Crawford (1991b) models, though while Talin (1994) treats the distinction as a quantitative and continuous one, Crawford treats it as a qualitative and discrete one.

Another conceptual scheme that is useful for understanding the differences between game genres is Gingold's (2003), who suggests there are four variables that determine the player's point-of-view on the gameworld. These variables are epistemic access, locus of manipulation, player character, and identification. *Epistemic access* refers to what the player can see of the gameworld. For example, is the world depicted in two or three dimensions? Does the player view the world from the first-person perspective (i.e. through a game-character's eyes, as in a first-person-shooter or driving game) or from the third-person perspective (i.e. looking down on the gameworld, as in a shoot-em-up or real-time-strategy game)? *Locus of manipulation* refers to what aspects of the gameworld the player controls and how the player controls these aspects. For example, do the players of a game control a single game element all the time (as occurs in many first-person shooters), do they partially control multiple elements (as occurs in most strategy games), or are they able to sequentially control many different single elements (as occurs in many action/puzzle games)? *Player character* refers to how, if at all, the player perceives themselves to be located in the gameworld. The player character is frequently the same as whatever it is that the player manipulates, but this is not always the case. In puzzle games such as *Tetris* or *Puzzle Bobble*, for example, the player does not have a character, or else the character is not what the player manipulates. Finally, *identification* refers to what the player cares about in the game. The player always cares about what it is that they manipulate, yet because this is not always the same as the player character the player can also care about this character too. Moreover, because the player can manipulate elements within a large and complex whole (such as in *SimCity* or *Civilization*), they may not identify with these elements so much as with the whole.

That Talin (1994), Crawford (1991b) and Gingold (2003) can collectively propose such different conceptual schemes for understanding game genre illustrates what complex and multifaceted entities digital games are. While each scheme provides us with some insight into the similarities and differences between genres, neither individually nor collectively do they categorise all existing games. No attempt has been made in this thesis, therefore, to independently theorise regarding genre, and below, where some of the main genres of games shown in Table 2 are discussed, only the briefest of outlines is provided regarding the nature of each genre.

## Action

Action games engage the player in "lots of frantic button pushing" (Rollings & Morris, 2000, p. 8) and hand/eye coordination tasks, though the particular nature of the task being performed varies considerably across the action sub-genre (which include *shoot-em-ups*, *first-person-shooters*, fighting games, *platformers*, and also some types of puzzle games. Shoot-em-up games often involve the player in controlling some sort of armed vehicle which shoots at enemies that approach. *Space Invaders* was an early shoot-em-up game. In first-person-shooters the player views the gameworld in the first person (i.e. as if they were looking at the gameworld through the game character's eyes) and they engage in armed combat with other inhabitants of the gameworld. *Doom* was an early first-person shooter. In fighting games there are usually two combatants, viewed from the third-person perspective, and they fight each other hand-to-hand and/or using various kinds of weapons. *Mortal Kombat* is an example of a fighting game. In platformer games the player controls a character that runs through a complex and visually impressive environment, exploring this environment while collecting valuable items and eliminating enemies. *Super Mario Brothers* and *Sonic the Hedgehog* are examples of platformer games. Many puzzle games are action games, and a famous example of a puzzle/action game is *Tetris*. In this game the player manoeuvres falling blocks so as to fit them together, the blocks appearing more and more rapidly as the player progresses.

### Strategy

Also known as *real-time strategy games* (to distinguish them from turn-based strategy games, such as chess), this genre of games involves the player in making strategic and tactical decisions involving the allocation of various kinds of resources, both economic and military. *Civilization* is an example of a strategy game. Strategy games are highly process-intensive games and do not rely for their appeal upon visually interesting spaces as do action games. Strategy games often are set within actual historical periods and may even refer to actual military engagements (e.g. *Sid Meier's Gettysburg!*), yet the aim of such games is to create a situation "where you're not just going down the path of history", but rather where "you're creating your own history" (Meier, 2000, p. 36). Even strategy games that aim for historical realism, therefore, are still not like *stories* about military engagements.

### Adventure

Adventure games are the most story laden of all digital games. The earliest adventure games were completely textual, and text is still often used within such games, though now story is also communicated to players through game characters speaking and through game sequences known as *cut scenes*. Cut-scenes typically appear in the form of introduction and ending scenes (i.e. after the player has completed some part of the game) and are often like excerpts from films (Juul, 2001a). Like some action games, adventure games require the player both to explore the gameworld and to solve puzzles and problems within it in order to progress from one area to the next, and thus frequently these two genres are hybridised such that some first-person-shooter games are also adventure games (e.g. *Deus Ex*).

## Role-playing

In role-playing games the player creates a character with particular attributes and then engages that character in various adventures. Through these adventures the character is able to gain experience, weapons, useful objects, comrades, abilities and skills. *Everquest* is an example of a role-playing game and the *Everquest* website sums up the nature of the game:

> Welcome to the world of EverQuest®, a real 3D massively multiplayer fantasy roleplaying game. Prepare to enter an enormous virtual environment – an entire world with its own diverse species, economic systems, alliances, and politics. Choose from a variety of races and classes, customize your character, and begin your quest in any number of cities or villages throughout multiple continents. Equip yourself for adventure, seek allies and knowledge, and experience a rich world of dungeons, towers, crypts, evil abbeys – anything is possible – even planes and realities beyond your imagination. Meet new friends from around the world to face epic challenges. Make yourself a noble human knight, a vicious dark elf thief, a greedy dwarven merchant, or whatever suits your desire. (Sony, 2004)

A large part of the attraction of role-playing games is that they facilitate both players taking on new roles, and also social-interaction between role-players.

## Sports and Racing

Sports and racing games are action/simulation hybrids. These games are usually simulations since fans of any given sport (such as football, for example) are keen that the game be as similar to the reality as possible, but they also tend to be action games, requiring the player to engage in rapid hand/eye coordination tasks. In addition, many of these games also allow the player to engage in strategic decision making by allowing them to choose, for example, what players to place on a team or what competitions to enter their race-car in.

### Educational (Edutainment)

Edutainment is a form of educational game primarily purchased by parents or schools for their children/students with the desire that they will learn something while playing them. Edutainment is discussed in detail in Chapter Six.

## Simulation Games

Technically speaking it would be true to say that all digital games are simulation-games (or else simulacra♣-games) in that they are process-intensive games that mimic the behaviour of some more-or-less complex 'reality'. The term *simulation-game* is, however, generally used to refer only to those interactive entertainments that are both highly realistic and that present the player with a complex system that they can play with – like a toy – any way that they choose. In Chapter Two it was proposed that few games based upon scientific simulations (i.e. SciSim games) currently exist, yet at first glance it might seem that many simulation-games could be counted as SciSim games since many simulation-games attempt to realistically model some aspect of the world. Most of the games classed as simulation-games are not simulations of the unfamiliar systems

♣ Following Baudrillard (1994), "a copy without an original". In other words, many digital games simulate realities that do not actually exist: fantasy realities.

interesting to scientists, however, but are instead simulations of glamorous and/or exciting and inaccessible systems.

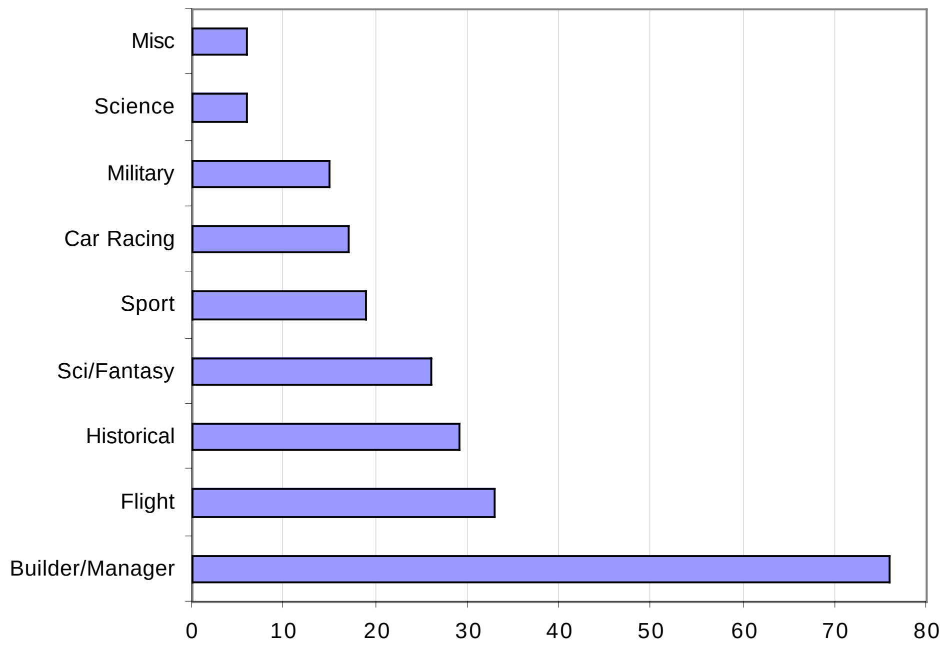


**FIGURE 6** – The popularity of various genres present in *About.com*'s Computer Simulation Games list (as per March 14, 2004).

Figure 6 shows the 227 games listed within *About.com*'s Computer Simulation Games pages♦ organized by genre, and as may be seen, science related games account for only 6 out of 227 (or less than 3%) of all games listed at this site. Moreover of these 6 games, 3 (*911 Paramedic; Emergency Room: Code Red;* and *CSI: Crime Scene Investigation*) deal with applied medical and forensic science, while a fourth (*Ant War)* is not at all realistic and is aimed at young children. It is thus only the other two science related games on the list, *SimEarth* and *SimAnt*, that deserve the title of *SciSim game*. Of course, there are other SciSim games (e.g. *SimLife*) that did not make it onto the

♦ Retrieved May 14, 2004, from http://compsimgames.about.com/library/blatoz.htm?PM=ss13_ compsimgames. The full list is provided in the Appendix.

About.com list, yet within the context of digital games as a whole their number must be very small. In 2002 only about 25% of all digital games sold were computer games (PCs being the type of hardware for which simulation-games are usually made) and of these only about 6% were simulation games (IDSA, 2002, 2003). Moreover, only a small fraction (if any fraction at all) of this 6% would have been SciSim games, considering that the only two SciSim games on the *About.com* list were published in the early 1990s. Thus, while the actual number of SciSim games in existence cannot be stated with any assurance, this number is a small one and in recent years has only been growing slowly.

Since only a small number of SciSim games currently exist no compelling empirical evidence can be provided for their efficacy in communicating science, yet it will prove worthwhile to briefly look at a few of them (i.e. *SimEarth*, *SimLife*, and *SimAnt*), both in order to gain a more concrete sense of just what such games can be like, and also in order to understand why they were not especially successful in the marketplace. It will also prove worthwhile to look at some simulation-games that were successful in the marketplace (i.e. *Microsoft Flight Simulator*, *SimCity*, *Civilization*, and *The Sims*): again, to gain to a more concrete idea of what simulation-games can be like, and also in order to see what attributes make for a popular simulation-game. In addition, a popular web-based SciSim game (i.e. *sodaplay*) will be discussed.

## SimEarth – The Living Planet

Co-created by Will Wright, author of *SimCity*, *SimEarth* was first published in 1990 by Maxis games. In the same way that *SimCity* lets the player build and manage a city, or that *The Sims* lets the player build and manage a household, *SimEarth* lets the player build and manage a planet with the aim of nurturing intelligent life. At the beginning of the game the player is presented with a series of scenarios: continent creation; terraformation of Mars or Venus; assisting human society to evolve out of the stone age; and experimental mode. Having chosen one of these options the player is then presented with a planet and can alter various aspects of its geological, atmospheric, and biological functioning.

With regards to the geosphere the player can alter the rate of volcanic activity, erosion, continental drift, or meteor impacts. With regards to the atmosphere the player can alter solar input, rainfall, cloud and surface albedo, and air-sea thermal transfer. With regards to the biosphere the player can alter the reproduction rate and mutation rate of the various species of animals (e.g. bacteria, insects, mammals, arthropods) and vegetation with which they populate the planet. The player can also seed human civilisations of various levels of complexity (such as stone age, iron age, industrial), can choose the sources from which the more advanced civilisations obtain their energy (e.g. solar, wind, hydro, fossil fuels or nuclear) and can also determine how they will allocate this energy between a variety of different investment areas (e.g. philosophy, science, agriculture, medicine, art/media). Finally, the player can cause various kinds of natural disasters (e.g. earthquakes, tidal waves, and plagues) to occur on the planet. The player is able to find out detailed information about the planet's geo-, bio-, atmo-, and hydro-spheres by calling up various graphs, tables, and charts. So for example, the player is able to call up charts showing changes over time to sea temperature, use of fossil fuels, and levels of CO2. Figure 7 shows a screenshot from *SimEarth*.

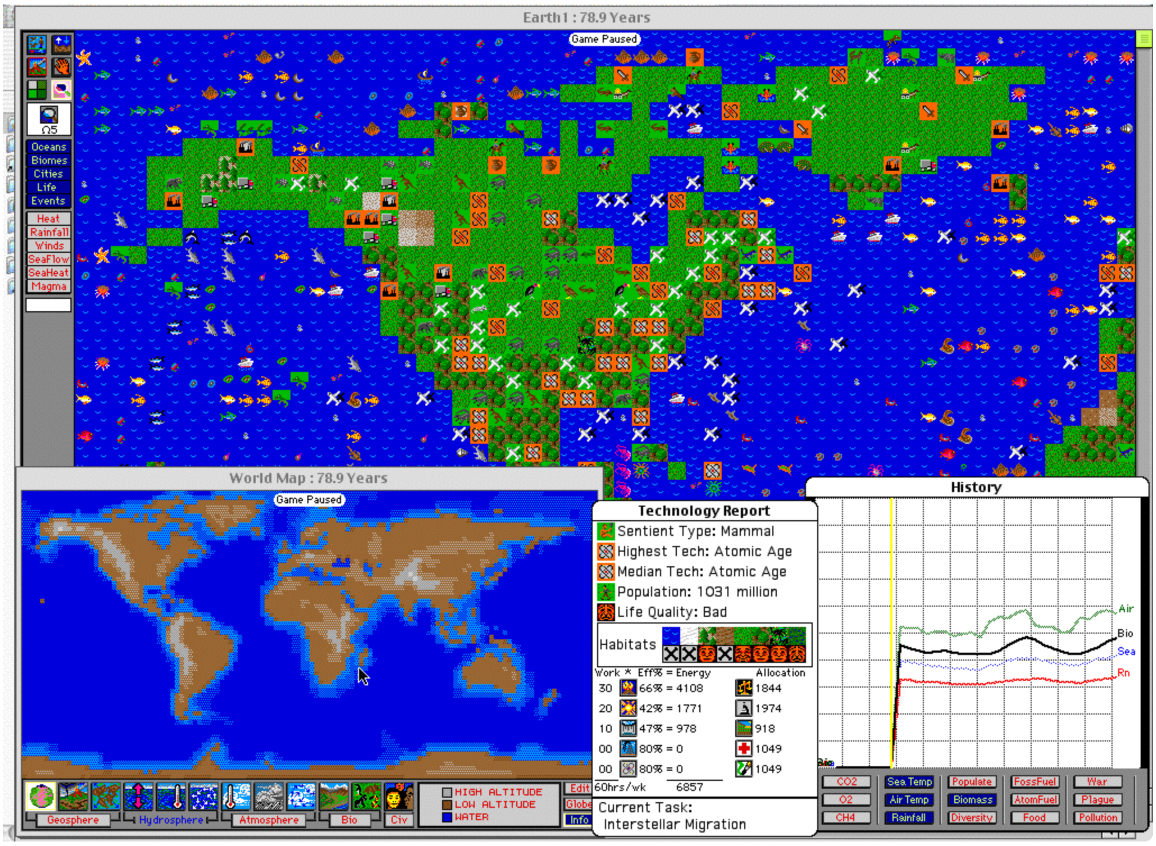


**FIGURE 7** – *SimEarth* screenshot.

With respect to why this game was not at all popular, comments such as the following are indicative:

> No one likes this game except for me apparently, but it is one of my all time favorites. Yes it is fast, and yes it is EXTREMELY difficult to play . . . This is not a game as such, . . . You can't win, there are no points . . .This is the type of game which takes hours and hours to understand, and takes even more and more hours to play. The only way to create a viable ecosystem is constant monitoring and

> tweaking, and making lots of mistakes and accidental successes. It can be frustrating at times, but the result is an ecological education, and a sense of pride at discovering the various vagaries and details while keeping a planet in balance. This is one of the hardest "god-games" out there – but who said that being a god was easy? (Haire, 2000)

Similar sentiments are expressed by Will Wright, the designer of the game:

> I was very proud of the simulation of *SimEarth*, and pretty disappointed in the game design. . . . It wasn't a terribly fun game . . . The biological systems tend to be very soft, squishy things that you can do something to and then it kind of reacts and adapts. It's not really clear what you did to it, because it'll then evolve around you. . . . [W]hen you get into complex things like diversity, food webs, and things like that, people just don't have an instinct for it . . . When SimEarth came out I realized at the end that, God, this is like sitting in the cockpit of a 747 in a nose dive. That's what it feels like to most players. (Wright, 2000, pp. 443-447)

The main problems with *SimEarth* are the complexity of the simulation and of the controls available to manipulate it. For the beginner user who knows nothing at all about surface albedo and mutation rates, let alone the way they affect the development of life, it is confronting in the extreme to be presented with the ability to alter these (and many other such) variables. This is particularly the case when the goals that the *SimEarth* player is trying to accomplish are unfamiliar and abstract, the process of accomplishing those goals is completely mysterious, the system being manipulated is so complex that even an expert will not always maintain control of it, and the game's graphics are insufficient to keep the player adequately informed regarding what is going on. Given these many grave problems, then, it is unsurprising that *SimEarth* should have proved to be an unpopular game.

## SimLife

Published by Maxis games in 1992, *SimLife* is similar in many ways to *SimEarth* but is more complex and deals with life processes in more detail. This simulation provides the user with a very large number of variables to control. Some of these relate to the overall structure and function of the simulated world (e.g. world size, how mountainous, how hot, how moist, how many rivers and lakes, how many toxins and mutagens, level of weather variation), while others relate to overall *life physics* (e.g. movement costs, metabolism costs, health costs, food values of animals and plants). The options that the player is most concerned with, however, are those relating to the construction of lifeforms. A *biology lab* provides the user with precise control over the kinds of animal and plant species they produce. So for example, the player can create animals with various: levels of intelligence, types of diet, modes of locomotion, habitats, gestation periods, and numbers of offspring. Similarly, the player can create plants with various: morphologies (e.g. grass, shrub, tree), methods of seed dispersal, germination conditions, climatic habitats, ecological niches, and sprouting, flowering and seeding seasons. Having created a virtual species the player then places it within the virtual world and watches it evolve within that world, consuming and being consumed by other life forms. Figure 8 shows a screenshot from *SimLife*.

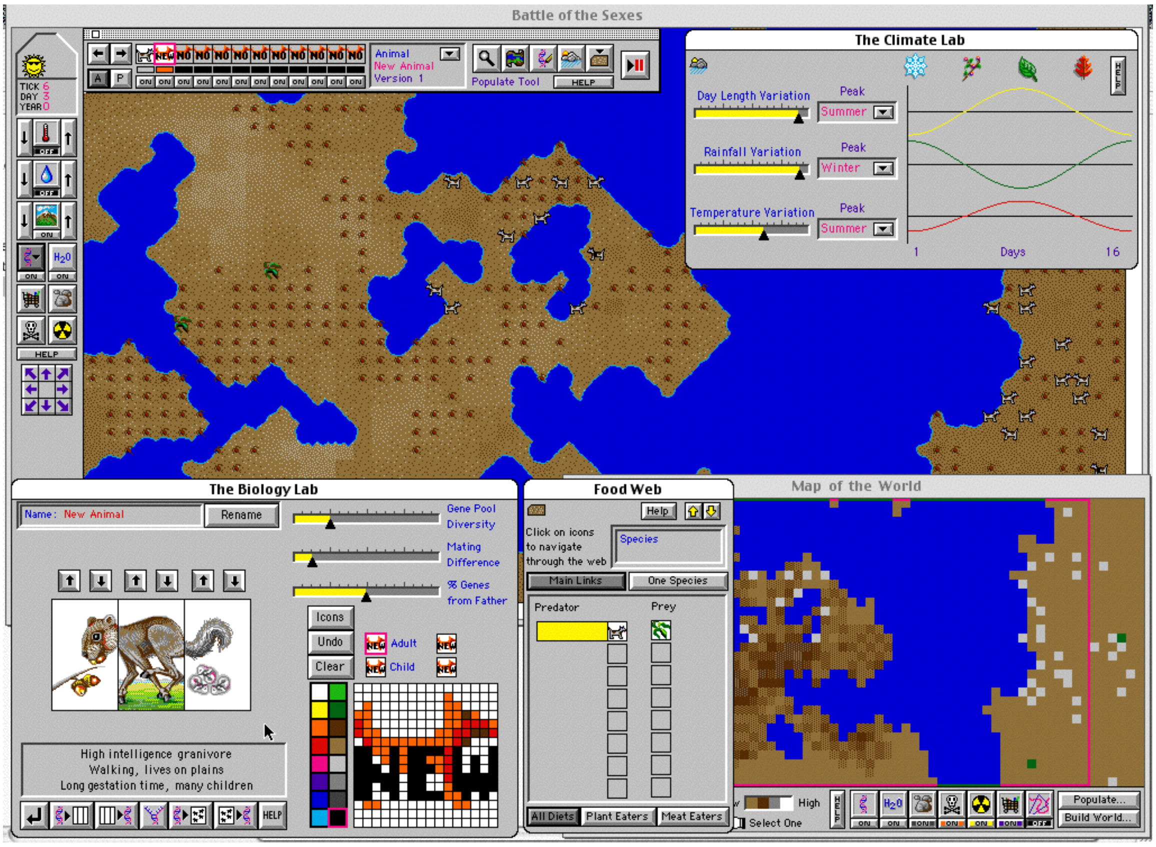


**FIGURE 8** – *SimLife* screenshot.

As to why this game was not especially popular, the reasons are simply more extreme versions of those that applied to *SimEarth*. The following comment from a user makes this clear:

> SimCity was a massive success. It blended a legitimate, applicable intellectual challenge with a fun, rewarding gaming experience. For many years, Maxis had difficulty reproducing or improving this winning formula. Throughout the early 1990's, they tried a variety of different balances between higher and lower order intellectual challenges. SimEarth was a bit pedantic and burdensome, but it had an inkling of a fun factor. SimAnt had a lot of action, and it taught you a lot about ants, but the intellectual scope was a little limited. SimLife was the concept taken in the wrong direction, in the extreme. SimLife was incredibly complex, terribly slow, aggressively educational, and boring. . . . Playing this game for a few hours feels more like a college problem set than leisure time, because that's what it is. It's a task and a chore, not a game. (Dawg, 2002)

In a similar vein, but more tersely, another user comments that "I would rather chew off my own foot than play this game ever, ever again".♣ Once more, extreme complexity (of both model and controls) coupled with inadequate graphics and a lack of clear goals results in a game that takes a long time to learn how to play, is slow, too complex to keep track of, unrewarding, overtly educational, provides poor feedback, and is enjoyable only for those with a keen interest in biology.

## SimAnt

Co-authored by Will Wright and published by Maxis in 1991, *SimAnt* enables the player to be the guiding intelligence behind a simulated ant colony. The player can choose from amongst a number of game scenarios when playing: experimental, war between black and red ant colonies, and taking over a human household. The player influences events in the black ant colony by taking over control of one of the ants. Should this ant die the player is reborn as a new black ant. Using this ant the player can show the other black ants where food sources are and recruit them to collecting food using pheromone trails. The player can also lead the black ants to war against the red ants and must assist the black ants to avoid being eaten by spiders, ant lions, and red ants.

Apart from acting within the gameworld directly as one of the ants, the player is also able to exert control over the behaviour of the black ant colony through determining its resource allocation and reproductive strategies. With regard to the former the player can determine how much time the black ants allocate to foraging for food, digging tunnels,

♣ http://www.gamers.com/userreview/1343898 or nursing new ants. With regard to the latter the player can determine what proportion of ants born into the black nest are workers, soldiers, or breeders. Available to the player are a host of statistics on the overall performance of both ant colonies, including population size, overall colony health, collected, stored, and consumed food, number of ants expired and killed, number of eggs hatched and number of fights won. Figure 9 shows a screenshot from *SimAnt*.

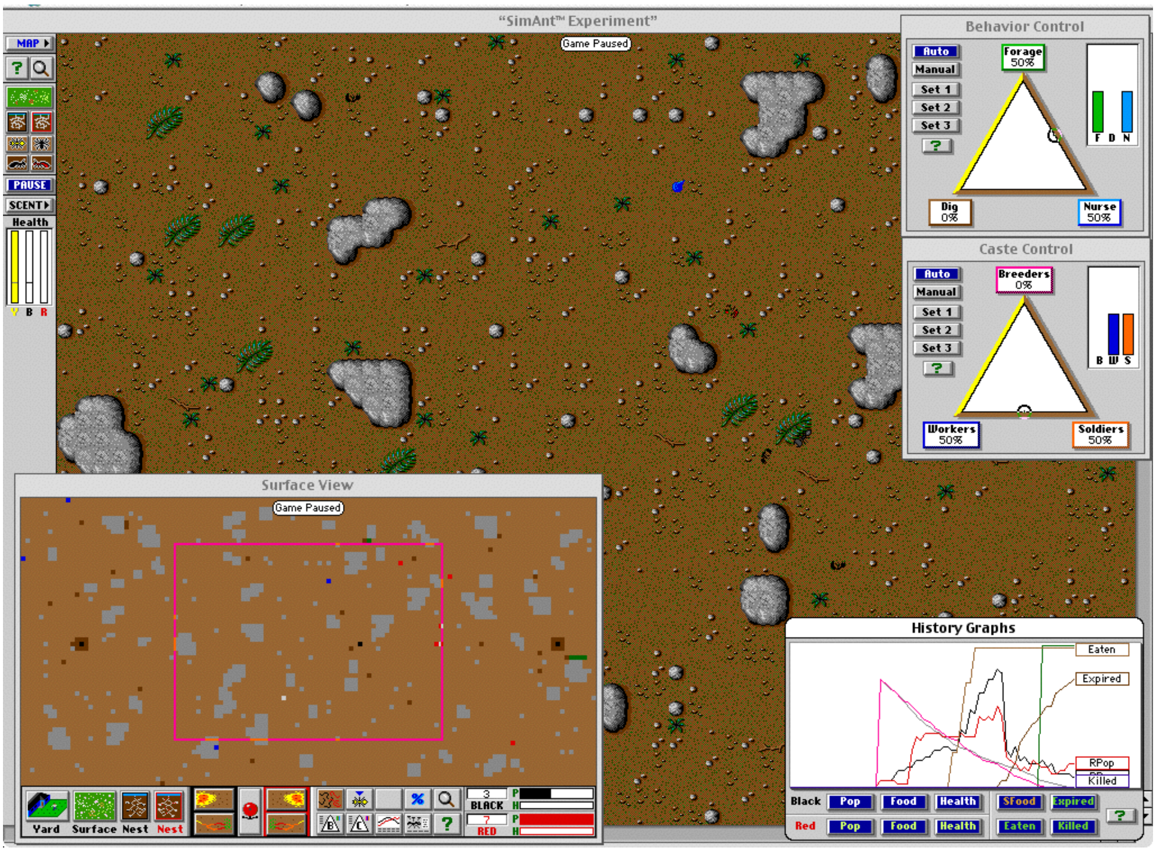


**FIGURE 9** – *SimAnt* screenshot.

Compared with *SimEarth* and *SimLife* (and as evidenced by reviews available on the web)[♣], SimAnt was a much more popular game, even though it was not especially popular within the context of games in general. Players enjoyed seeing the world from an ant's perspective and being able to interact with other insects, being able to kill a menacing spider, and being able to take over a house and garden. Players also enjoyed the game's *experimental mode* which allowed them to learn about ants and their world and to play freely with the simulation in a self-guided manner, much as if it were an 'ant farm'. Compared with *SimEarth* and *SimLife*, the model underlying *SimAnt* is relatively simple, the game presents the player with clear goals, and as a result the player's learning curve is comparatively shallow. For many players, however, this game did not present a sufficient challenge and quickly became boring.

## Microsoft Flight Simulator

The simulation game that eventually became *Microsoft Flight Simulator* was initially developed in the mid 1970s by Bruce Artwick, an electrical engineering graduate student at the University of Illinios. It was developed as part of his master's thesis, called "A versatile computer-generated dynamic flight display". In 1978, Artwick and a collaborator founded a software company by the name of *SubLOGIC* and in January 1980 *SubLOGIC* released the first version of their flight simulator (soon to be licensed and published by another newly created software company, *Microsoft*) (Grupping, 2001).

> In January 1980 SubLOGIC FS1 hit the consumer market. By 1981 Flight Simulator was reportedly the best selling title for the Apple.

[♣] See http://www.epinions.com/pr-SimAnt_For_Windows_Mac/display_~reviews

By the end of 1997 Microsoft claimed to have sold not less than 10 million copies of all versions of FS, making it the best sold software title in the entertainment sector. And in 2000 Microsoft Flight Simulator was taken up in the Guinness Book of Records with 21 million copies sold per June 1999 (Grupping, 2001).

**FIGURE 10** – Screenshot from *Microsoft Flight Simulator 2002*♠

The core experience that *Flight Simulator* offers is the ability to fly a realistically simulated aircraft within a realistically simulated world, and the level of realism has improved with every edition. Among the realistically simulated features are the physical dynamics of the aircraft, the controls, instruments, and radios, meteorological conditions, airports, and with the 2004 edition, air traffic control and the intelligent non-

♠ Retrieved November 07, 2003, from http://www.microsoft.com/games/fs2002/screens/fs2002screen_fog_KSFO5_med.jpg.

player aircraft. Among the possibilities for customisation offered to the player are a wide choice of aircraft, a huge choice of airports, detailed meteorological control, and the ability to cause a variety of engine, instrument, and other failures to occur. Figure 10 shows a screenshot from a recent version of *Microsoft Flight Simulator*.

## SimCity

The first incarnation of *SimCity* was created for the *Commodore 64* computer in 1985 but it was not until four years later that the game was finally published. The reason for this long delay was a lack of publisher interest which itself was due to *SimCity* being a game unlike any other of its time. Most games, then and now, involve the player in various types of 'kill or be killed' activity, but in *SimCity* the player's goal is to build something: to build and manage a functioning city.

When it was first released sales of *SimCity* were slow, but after it was written about in a *Newsweek* magazine article it became very popular, and not just with regular game buyers. In fact, the original version of *SimCity* was also popular with teachers as an educational tool and ended up in over 10 000 school classrooms, which even today is an impressive feat. The next version of *SimCity*, *SimCity 2000*, was even more popular than the first and when it was released in 1994 became the top selling game in the world for six months (Maxis, 2003). Since that time, two further versions have been released: *SimCity 3000* (in 1999) and *SimCity 4* (in 2003).

The task of the player of *SimCity 2000* is to both create and manage a city. At the beginning of the game the player is presented with a large and empty area of wilderness.

Using various tools they are then able to alter the terrain, plant trees, add water courses and services such as powerlines and power plants of various types (e.g. coal, hydro, nuclear), water-pipes, -towers, and -pumps, roads and tunnels, railroads and depots, seaports and airports. Moreover, the player can zone land in a variety of ways, i.e. as:

- Residential (low/high density)
- Commercial (low/high density)
- Industrial (low/high density)
- Educational (containing schools, colleges, museums, and libraries)
- Health and Safety (containing police and fire stations, hospitals, and prisons)
- Recreational (containing zoos, marinas, stadiums and parks).

Citizens in the simulated city live in the residential zones, work in the commercial and industrial zones and, as a result of taxes placed upon commerce and industry, are able to pay for the activities in the education, health and safety, and recreation zones. The player can set differing taxes on (and thus provide differing levels of support for) the various types of commerce (e.g. tourism, electronics, finance, media) and industry (e.g. aerospace, automotive, construction, petrochemical, textiles, steel/mining) that can operate within the *SimCity*. These differing types of commerce in turn make a city more or less pleasant to live in.

To assist their decision making regarding what sorts of infrastructure to build, how to handle zoning, and what sorts of commerce to encourage, players can obtain all kinds of statistics regarding the state of their city, the proportion of businesses in each of the various sectors, demographic information and other indicators of the 'health' of their city. Figure 11 shows a screenshot from *SimCity 4*.


**FIGURE 11** – *SimCity 4* Screenshot♠.

## Civilization

*Civilization* began life as a board game, published in 1980 by *Avalon Hill*. The first computer version of the game, created by Sid Meier, was released in 1991. It was followed by *Civilization II* in 1996 and *Civilization III* in 2001. Like *SimCity*, *Civilization* has been a massively popular game, with over 4 million units sold♣ and has

♠ Retrieved November 12, 2003, from http://www.simgaming.net/simcity3000/screens/sc3k2.jpg.
♣ According to the official website (http://www.civ3.com/faq.cfm).

ranked high in a variety of 'greatest games of all time' polls since its initial release (Dumell, 2001).

Unlike the beginning of *SimCity*, the player of *Civilization* begins the game without any knowledge of, and minimal control over the gameworld.  Apart from one small square of land the whole screen is blacked out.  The player begins with a single resource – settlers – and using these settlers they must first explore some of the gameworld until they find a suitable location to build a city.  The choice of where to build a city is determined by the terrain.  There are different terrain types (e.g. artic, desert, forest, grassland, tundra, mountains) that are associated with different movement costs, with different levels of defence, different food and mining production values, and that are differentially facilitative of trade.

Having established a city the player then has a number of options regarding what that city will produce.  For example, in the early stages of the game it can produce settlers, a military, or various kinds of buildings.  Settlers are needed to establish more cities, to grow crops, and to construct roads and irrigation.  A military is required to construct fortifications and to attack other civilisations.  Buildings such as granaries are required to store grain from harvests.  Because resources are limited, because it takes time to produce settlers, troops, and buildings, and because other neighbouring civilisations are also growing and developing (and perhaps threatening), the player must constantly evaluate their situation to decide what type of production is most important.

Apart from the choices above, the player is also able to invest resources in scientific research and as a result of the discoveries made through this research their civilisation may become more technologically advanced.  Another way of obtaining new technologies is by trading with other civilisations, and military pacts can also be formed with these civilisations.  There are many more complexities to this game than can be elucidated here and the player is constantly required to understand these complexities in order to be successful.  Figure 12 shows a screenshot from *Civilization III*.


**FIGURE 12** – *Civilization III* screenshot♠.

♠ Retrieved November 07, 2003, from http://www.civ3.com/gallery.cfm.

## The Sims

First released in 2000, *The Sims* (along with its six expansion packs and three console versions) has been an exceptionally popular game, with over 15 million units sold up to October 2003.♣ Created by Will Wright, the creator of *SimCity*, *The Sims* is concerned with the functioning of a household. The player of *The Sims* begins by designing the personalities, skills, and appearances of one or more Sims (i.e. simulated people). The player is then able to move their Sims into pre-built homes, or else the player can design a home for them from the ground up. After this the player's next task is to manage the lives of their Sims, to help them pursue their careers, make friends, and find 'romance'. The player does not have total control over what their Sims do – since the Sims are to some degree autonomous – yet they are rather inept and will survive better if the player pays attention to meeting their various physical and psychological needs. One attraction of *The Sims* is that players are able to create Sim objects (e.g. faces, clothes, consumer durables of all kinds) and then post them onto the Web so that other players may use them. Due to be released early in 2004 is *The Sims 2*. This sequel will allow the Sims to age, to have children who will inherit the physical and psychological characteristics of their parents, to have more realistic facial expressions, and to accumulate a *life score* that will provide a measure of how successful the Sim has been in accomplishing their goals. Figure 13 displays a screenshot from *The Sims*.

♣ According to The Sims website, http://thesims.ea.com/us/news/simsps2_pressrelease.html, Retrieved December 25, 2003.


**FIGURE 13** – *The Sims* Screenshot♠.

With respect to the question of why *Microsoft Flight Simulator*, *SimCity*, *Civilization*, and *The Sims* have all been more successful than have *SimEarth*, *SimLife*, and *SimAnt*, a simplistic answer to this question is that the former set of games were simply *better games* than were the latter set. Treating the matter somewhat more deeply, however, we can say that *SimLife* and *SimEarth* (in particular) were *poorly designed* games because they did not present the players with familiar goals, their focus was too broad, they were too complex, and because their design stressed realism over entertainment.

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♠ Retrieved November 08, 2003, from http://www.gamershell.com/hellzone_Sim-Tycoon_The_Sims.shtml.

When game players, prior to playing a game, already possess a collection of goals applicable to its gameworld and some sense of how these goals might be accomplished, then they can begin enjoyably playing that game very quickly.  New players of *The Sims*, for example, already desire their Sims to be wealthy, popular, beautiful, 'successful', and so forth, and they realise that in order for their Sims to accomplish these goals they will have to develop careers, have friends, take care of their appearance, and so forth.  When they are presented with controls governing these attributes of their Sims, therefore, new players of *The Sims* already know how to use them.  Contrast this situation with that faced by the new player of *SimLife*, whose goal it is to create a balanced ecosystem or to evolve a new lifeform, and who can do so by, amongst other things, determining *life physic*s and *gestation periods*.  The new player of *SimLife* is unlikely to already desire to create a balanced ecosystem or to evolve a new lifeform, they are unlikely to already know how to accomplish such goals, and therefore it will take them some time to learn how to make use of the controls that *SimLife* provides them.  Since learning how to use a game's controls tends not to be an enjoyable activity, however, games such as *SimEarth* and *SimLife* have tended not to be popular games.

That the goals of *SimLife* and *SimEarth* (e.g. balance an ecosystem, terraform Mars) are not familiar to players is mainly because these games are not focused enough.  If *SimEarth* had, for example, been designed to focus upon a *particular* aspect of the Earth's behaviour, such as continent building, then the player could have had the goal of attempting to create various kinds of landforms (such as mountains, lakes, plateaux, and valleys), and such a goal would have at least been comprehensible to many people.

Instead, however, *SimEarth* was concerned with not only geological, but also atmospheric, oceanic, and biological processes, and thus it presented the player with too many possible goals and did not allow them to focus upon any one of these goals to any extent. Similarly, if *SimLife* had been designed to focus upon the evolution of a *particular* kind of animal (such as a dog), then the player could have had the goal of attempting to create various kinds of dogs (such as hunting dogs, lap dogs, racing dogs, etc.) and such a goal also would have been comprehensible to many people. Instead, however, *SimLife* allowed the player to design landforms, to determine climatic conditions, to determine fundamental life dynamics, and to alter a vast number of lifeform parameters, and thus (again) it presented the player with too many possible goals and did not allow them to focus upon any one of these goals to any extent.

Not only does a game's lack of focus interfere with the player establishing meaningful goals, it also tends to ensure that the player will face too much complexity to accomplish those goals. Both *SimLife* and *SimEarth* were extremely complex games (i.e. they were based upon complex underlying simulations), and as a result, their players were confronted with numerous controls whose affect upon the game system was difficult to determine. Now, even under the best of circumstances it is difficult to convince players to take the time to learn how to use new controls, but when there are many controls and it is unclear exactly what they do then most players will give up the attempt entirely. This is what happened with *SimLife* and *SimEarth*.

Perhaps the main reason that *SimEarth* and *SimLife* lacked focus and ended up so complex is that their designers were more concerned with realism than they were with entertainment. When one sets out to design a game based upon a scientific system there is always a tension between whether the game or the simulation will take precedence. If the game is an educational game then the simulation should take precedence but if the game is a SciSim game then the game should take precedence. This is not what happened in the case of *SimEarth* and *SimLife*, however. As the designer Will Wright notes:

> . . . I was very proud of the simulation of *SimEarth*, and pretty disappointed in the game design. It wasn't a terribly fun game. It's actually a very nice model, and we did a lot of research of the current climatic models, and I have still never seen anyone do an integrated model with an integrated lithosphere, hydrosphere, and atmosphere together like that. And we were getting some effects in the model that were real effects, that really show up, that even some of the more elaborate models that NCAR [National Center for Atmospheric Research] makes weren't capturing. (Wright, 2000, pp. 443-444)

While scientific realism of the kind that Wright describes can make for an excellent educational simulation, it is completely unsuitable for a SciSim game, and *SimEarth* is a poor SciSim game precisely because greater concern was felt for its scientific realism than for its entertainment value.

## Sodaplay

*Sodaplay* is not a simulation-game in the same sense as the games above, but what makes it worthy of interest in this context is that it is a *Java* based game. *Java* is both a programming language and a software-based platform (meaning that it is a platform for programming that runs within an operating system). So long as one's computer has the

Java platform installed (and both *Microsoft* and *Apple* package this platform along with their operating systems) then programs that are written in the *Java* language will run on it. Most *applets* (small programs downloaded from the web and (usually) run within one's web-browser) are written in either *Java* or else in *Flash* (another software technology with similar capabilities to *Java*). A second difference between *sodaplay* and the other games discussed earlier is that it is free: one simply accesses the *sodaplay* website, downloads the *sodaconstructor* applet, and begins to play.

According to the *sodaplay* website (www.sodaplay.com)(which deliberately used lower caps) "sodaplay was devised by a london based company called soda creative ltd. we made it as part of our ongoing ideas generation, research and development process, but mainly we made it just for fun." At the time of writing, the only apparent source of income that soda creative ltd. derives from *sodaplay* is through the online sale of t-shirts that depict various *soda* constructions. It is safe to assume, however, that the popularity of *sodaplay* has generated clients for other aspects of soda creative ltd's business. Says their website:

> soda has been pioneering new experiences through digital media since 1996. we combine an arts and research practice with a broad range of commercial activities, encompassing ideas generation, digital design, content creation, software production, art commissions and research and development. soda are actively seeking clients and partners. if you like sodaplay and think soda could work for you then do get in touch.

With regards to its popularity, the *sodaplay* website reports that within a month of *sodaplay* first making an appearance on the web (in April, 2000) over a million people began using the software, and in April 2002 *sodaplay* was listed as one of Time Magazine 's 50 Best Websites.

Using the sodaconstructor program (Figure 14) the user can construct a moving creature from simulated masses, springs, and muscles. The user can also alter various global parameters such as gravity, friction, spring stiffness, and the rapidity of muscular contractions. Despite the simplicity of their components, these creatures can exhibit some surprisingly lifelike behaviours. As the *sodaplay* website notes:

> looking at the fluid, lifelike way these creatures walk and roll and slink across the screen you might think that there must be some very complicated stuff going on behind the scenes. well fear not, it's actually very simple. it only looks complicated because lots of simple bits are working together. when simple bits work together you can get emergent behaviour. that means that the system as a whole can be more complex and sophisticated than the simple bits that it's made out of..

Having designed a creature, *sodaplay* allows the user to send it in via e-mail for potential inclusion within the *sodazoo*, an online database of *sodaconstructions*. The user can also enter their creature into *sodarace*, an ‘online Olympics’ within which sodaconstructions are raced against each other over a two dimensional terrain, and within which sodaconstructions designed by humans are raced against others designed by artificial intelligence.

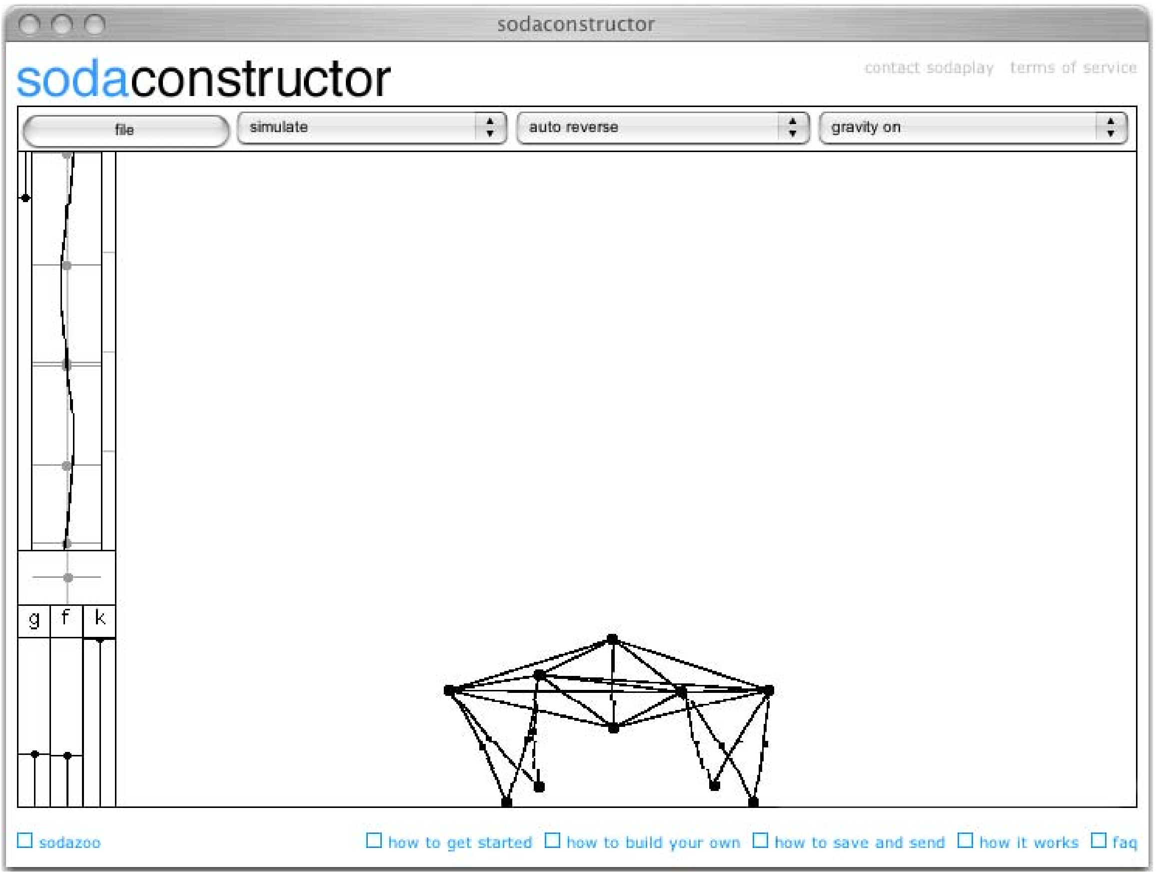


**FIGURE 14** – The *sodaconstructor* applet[♠].

Despite the fact that the sodaconstructions that users develop using *sodaplay* need not be models of real objects, nonetheless *sodaplay* may usefully be considered a SciSim game because of the unfamiliarity of the systems upon which it is based, and because these systems incorporate scientific elements (e.g. gravity, friction, muscular contraction, spring stiffness). *Sodaplay* has managed to be popular (where *SimLife* and *SimEarth* were not) because not only is the complexity of its underlying simulation manageable for beginners, but also because it provides players with goals that they desire to

♠ Retrieved December 10, 2003, from http://www.sodaplay.com/constructor/index.htm.

accomplish and with an intuitive means of accomplishing them. New visitors to *sodaplay* are immediately able to see numerous interesting objects that may be constructed using it, and thus the objects stored in the *sodazoo* act as both an enticement and a challenge. Additionally, because *sodaplay* is web-based it is capable of attracting players from all over the world who would never purchase it as a game, and thus its potential impact is considerable for a game that is both (comparatively) simple and inexpensive to produce.

# The Users of Interactive Entertainment

One indication of the popularity of digital game playing may be gained by studying the penetration of PCs and consoles into households.♣ As Figure 15 indicates, as of 2001 game consoles existed in about 30% of American households, as compared with video cassette recorders, which existed in about 90%. The penetration of PCs, and especially of PCs connected to the internet, is growing rapidly, yet PCs are used for other purposes besides games. As was indicated in Figure 3, many more games are sold for consoles than are sold for PCs, and the PC is apparently declining as a game-playing machine while increasing numbers of games are being sold for consoles.

♣ The statistics presented throughout this sub-section relate only to usage within the United States (the largest and best studied game market). Moreover, 88% of all computer and video game sales within the U.S. were made in the state of California in 2000 (IDSA, 2001a), though according to the 2000 census California possessed only 12% of the U.S. population. The true state of affairs in the U.S., not to mention the rest of the world, is thus unclear, and these statistics are therefore presented only to help the reader gain a general idea.

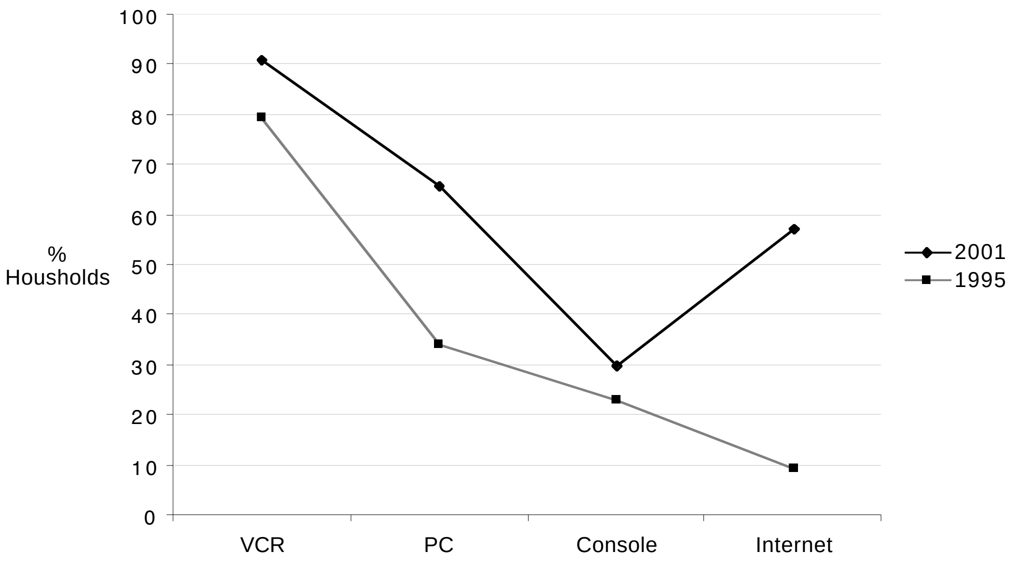


**FIGURE 15** – Penetration of various technologies into U.S. households 1995-2001 (Alexander & Associates, 2001; Motion Picture Association [MPA], 2002).

Another indication of the popularity of digital game-playing relative to other entertainment activities is provided in Figure 16, which shows that in 2002 digital games ranked below recorded music, about equal with books, and ahead of the cinema in terms of the number of hours spent per person using them. Usage of digital games is increasing, moreover, whereas usage of newspapers, magazines, and recorded music is decreasing. Some care does need to be taken when interpreting this graph, however, in that while the television, radio, and recorded music may all be used while engaged in other activities, this is not the case with the use of reading materials, the cinema, and game playing. The hours spent using the various media *in a devoted sense* are thus more equal than the graph indicates.

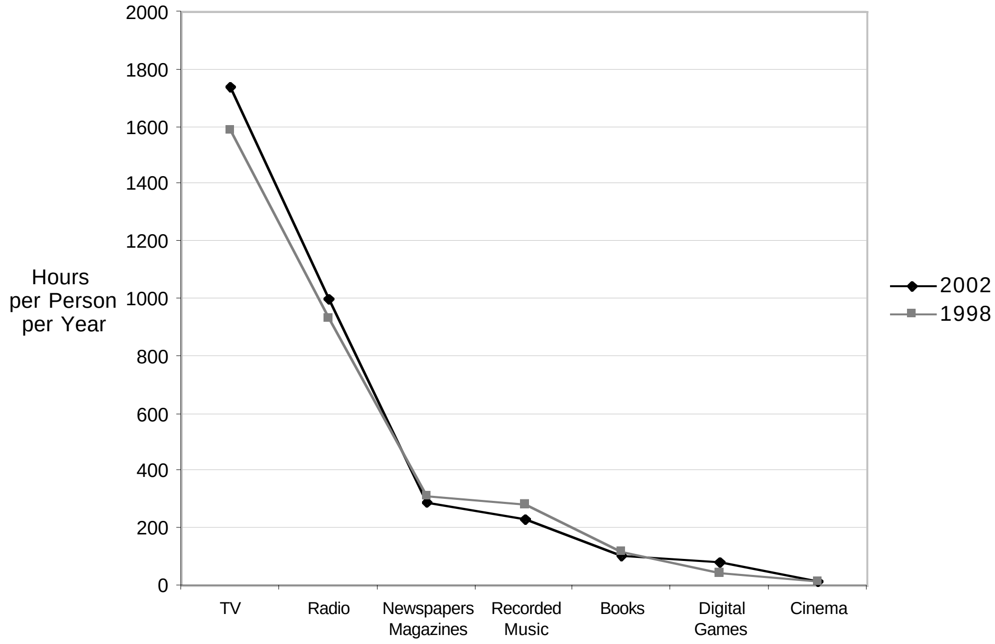


**FIGURE 16** – Media consumption for the average U.S. citizen in hours per person per year (MPA, 2002).

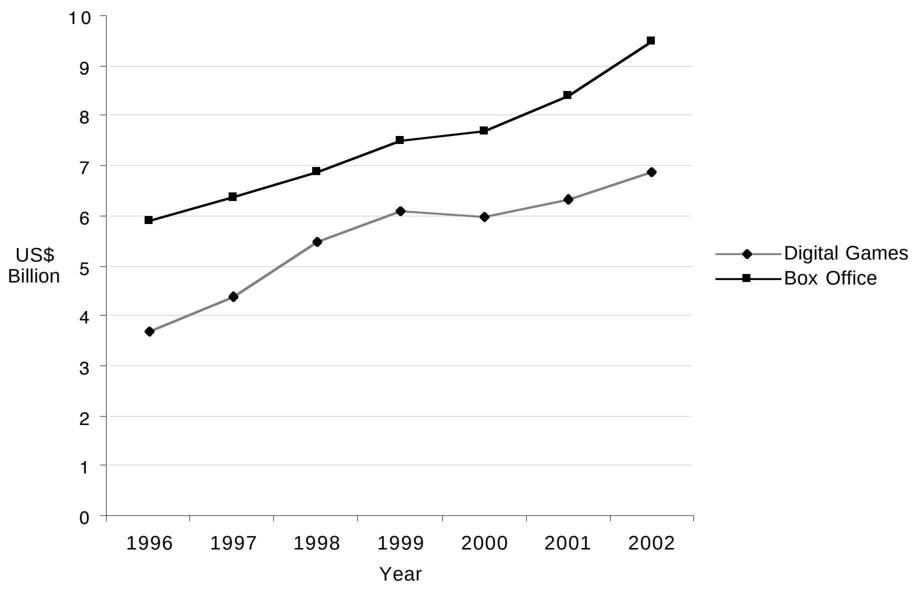


**FIGURE 17 –** Comparison of U.S. sales of digital games and cinema box office takings for years 1996 through 2002 (IDSA, 2003; MPA, 2002).

In terms of its overall revenues, the interactive entertainment industry is comparable with the cinema box office, as shown in Figure 17, and thus the production of games may rightly be thought of as 'big business'. Considering the production of games and films as separate activities is, however, somewhat problematic since many digital games are 'based upon' films (e.g. the many *Star Wars* games) and quite a number of films have been 'based upon' games (e.g. *Tomb Raider*) (cf. Bittanti, 2001). Additionally, the special effects used in films are produced using many of the same technologies as those used in games. Convergence of a similar sort has also been occurring between the music industry and the interactive entertainment industry, as popular music is often incorporated within games (cf. *Grand Theft Auto: Vice City*), while some music written for games becomes popular in its own right. As a result of such media convergences it is now often unclear whether a person is primarily listening to music, playing a game or watching a film, and it is thus also difficult to meaningfully segregate the revenues of the various entertainment industries.

The popularity of game playing varies by age, by gender, and as a function of general interest, and these three factors are discussed below.

## Age

With regard to the ages of players, because interactive entertainment as a popular medium is less that forty years old there are thus many adults over the age of forty who have never played a digital game. For many people below this age, by contrast, digital games are as familiar as television. Age is thus an important determinant of who uses interactive entertainment. Longitudinal and cross-sectional studies of children's videogame playing have found that total time spent playing video games increases with age from 2-7 years and then decreases again between ages 9 and 12 (Wright et al. 2001). It is thus within the under 18 age category that most *video* gameplaying occurs. By contrast, playing of *computer* games actually increases with age, and this is most probably because it is only the simulation-games available on computer that are able to provide adults with a sufficiently intellectual challenge. Figure 18 shows the percentage of the most frequent gamers in various age groups, for both consoles and PCs.

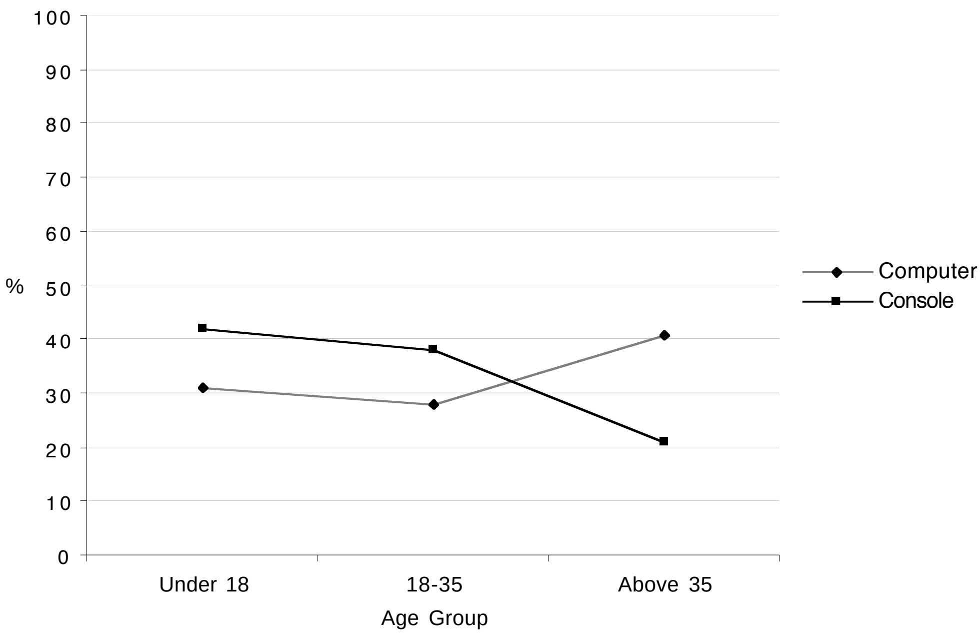


**FIGURE 18** – Percentages of digital game players by age group and platform.♣

## Gender

Before discussing gender differences in game playing it is important to note that historically, gender differences have existed in computer usage more generally.

♣ Composed of the averages for the various age groups across the IDSA surveys for 2001, 2002, 2003 (IDSA, 2001b, 2002; 2003). Age-group percentages were roughly constant across these years.

Historically, computers have tended to be used more by males, have been perceived to belong more to males, and computer science has been studied more by males (Cassell & Jenkins, 1998, cf. Schirra, 2001). Compared with males, females have tended to use computers less at home and at school, to know less about computers, to feel more anxious when using computers, to have more negative attitudes towards computers (Nelson & Cooper, 1997; Whitely, 1997) and to possess higher levels of technophobia (Brosnan & Lee, 1998). Females have also reported less comfort and competency with the internet (Schumacher & Morahan-Martin, 2001).

Cultural factors are likely to be the prime causative agents responsible for the gender imbalance in technology usage and the pursuit of technology-related education and employment. This can be stated with some degree of assurance because, while this gender imbalance has a longstanding existence within the countries of western Europe and North America, it did not exist within the former Soviet Union and communist bloc countries. Moreover, this gender imbalance quickly came into existence in these countries following the collapse of the communist system (Durndell, Cameron, Knox, Stocks & Haag, 1997). Among the cultural factors suggested as responsible for the gender imbalance are included " . . . the characteristics of boy's social networks, advertising, content of games, parental socialisation practices, and classroom management strategies by teachers, as well as a growing general cultural expectation of gender-typed usage" (Wright et al., 2001, p. 33).

While a recent report released by the Markle Foundation (Wartella, O'Keefe & Scantlin, 2000) has suggested that the gender imbalance in children's use of computers is now restricted only to games (and not to other uses), the gender imbalance in game playing is reasonably large. A survey conducted by the Kaiser Family Foundation (Roberts, Foehr, Rideout, Brodie, 1999) found that amongst 8-18 year olds, 60% of boys as compared with 21% of girls played video games, though only small differences were found in terms of computer game playing (boys 29% to girls 24%). Similarly, according to a survey commissioned by the Interactive Digital Software Association [IDSA] (2002), more males than females were video gamers (72% vs 28%), and more males than females were computer gamers (62% vs 38%). Other studies (e.g. Harris, 1999; Wright et al. 2001) have reaffirmed these findings.

Suggested reasons for the imbalance in game playing include that the type of aggressive and competitive challenge offered by many games is of more interest to men than women (Kaplan, 1983), that "games are gendered in such a way as to make them uninteresting and/or offensive to women" (e.g. by containing violent content and stereotypical or sexualised portrayal of women) (Bryce & Rutter, 2003, p. 7), that games do not possess content of interest to women and lack female characters, that the contexts within which gaming occurs are gendered (as masculine), that no one has tried making games specifically for women, that games are mostly made by men for men, that men don't know how to make games for women, and that the social practices of the male dominated games industry exclude females from making games (Bryce & Rutter, 2003; Cassell & Jenkins, 1998; Davis, 2002; Falstein, 1997; Gailey, 1993). Another suggested reason is the conservatism of game publishers and distributors. Since males have traditionally been the major consumers of digital games the types of game they play have become the default standard, and developers trying to create anything new immediately run afoul of publisher conservatism (Cassell & Jenkins, 1998; Falstein, 1997; Weil, 1997).

Because game playing is understood to develop certain cognitive skills (such as those relating to spatial abilities, problem-solving, and the ability to concentrate) (Aguilera & Mendiz, 2003; Gros, 2003; Lisi & Cammarano, 1996; Mayer, Schustack & Blanton, 1999; Pillay, 2002; Pillay, Brownlee & Wilss, 1999; Subrahmanyam, Greenfield, Kraut, & Gross, 2001), and because it also helps children to acquire a familiarity and ease with technology (which is of critical importance in the future, computing-oriented job market), the gender imbalance in game playing is seen by some as a social problem that requires fixing (Brzowsky, 1998; Vail, 1997). How to remove this imbalance remains a topic of debate, however, and for a number of reasons.

One reason relates to the idea that females, generally speaking, want different things from their games than do males. Doug Glen, president of *Mattel Media* (the makers of *Barbie* dolls) proposes in this regard that software designed for girls must be different than that designed for boys because girls and boys exhibit differing play patterns: they fantasise about different things, envisage different ways of accomplishing goals and differing ideal outcomes to situations (Meloan, 1996). Similarly, media-theorist Brenda Laurel proposes that girls enjoy complex social interactions, using their verbal skills, and engaging in fantasy play within familiar environments populated by characters that behave in familiar (i.e. realistic) ways (Beato, 1997). More comprehensively, Agosto (2003), in a review of the literature, found that girls favoured games that:

- eschew the conflict between good and evil.
- centre on storylines and character development.
- are not competitive in nature.
- use real-life locales.
- feature strong female characters who are in charge of decisions and actions.
- focus on human relationships.
- possess some educational value as opposed to being designed purely for entertainment.
- contain nonviolent action.
- reflect girls' common play patterns.

For some observers, though, such lists of differences suggest a biologically determinist perspective that limits the choices of females to those approved of by contemporary society. Eisenberg (1998), for example, feels that the differences between males and females are a result of culture and to design games based around these differences would be to reinforce these cultural stereotypes. Those games that have been aimed at girls, such as *Barbie Fashion Designer*, *McKenzie & Co.*, and *Let's Talk About Me*, she criticises as promoting sexist stereotypes, such as that girls are, or should be, interested in popularity, fashion, make-up, and 'dating' (cf. Jenkins, 1998; Weil, 1997) and rather than seeing the design of such games as a positive step forward, attracting girls to play games, Eisenberg sees it as a cynical marketing endeavour:

> [I]f a company can sell separate games to boys and girls, it can theoretically bring in up to twice as much revenue, by selling, for example, two different products to families with both sons and daughters rather than just one to share between them. And why not make use of commonly believed (but false) stereotypes of natural differences between the sexes to create that separate market for girls? (Eisenberg, 1998, p. 2)

The above comments suggest that one source of the conflict regarding the desirability of *girl's games* might be that the disputants possess quite different goals. That is, are such games to be developed to increase the number of girls playing games or are they to be developed so as to provide girls with positive social models (Cassell & Jenkins, 1998)? Those aiming only to increase the number of girls playing games, or those who simply want to make games for girls, will easily fall afoul of those who also possess the second objective because games concerning makeup, fashion, shopping and boys are what some (currently under-provided-for) adolescent girls want (Beato, 1997). Certainly it may be argued that such games do not provide girls with positive social models, yet this only places them on par with *boys' games,* which are notorious for not providing positive social models (Dill, Gentile, Richter & Dill, 2003; Vail, 1997; Weil, 1997).

A second point of contention in the debate about how to resolve the gender imbalance in game playing relates to whether games should be aimed specifically at girls or whether a more unisex approach should be taken. Henry Jenkins, co-author of the book *From Barbie to Mortal Kombat* (which deals explicitly with this issue of girl's games) notes:

> One of the most frequently asked questions when our book first appeared was whether it made sense to gender segregate, that is, to

> create a girl's market rather than expanding the existing boy's market to include more gender-neutral material. We were told, for example, that no one designed games specifically for boys. I would suggest that the release of a major piece of hardware known as the G*ameBoy* suggests that the industry did identify its products along gender lines. (Jenkins, 2001, p. 8)

That the themes of a variety of games (e.g. save the princess, find a girl to marry) implicitly posit a male protagonist (Consalvo, 2003) also suggests male gendering of products, as do content analyses performed on groups of popular games. One such analysis (Children Now, 2000) found that 92% of games had male lead characters, whereas 54% had female lead characters (some having both). Additionally, of all of the games that did contain female characters, half of them portrayed these characters as hypersexualised (i.e. with accentuated physical gender defining characteristics such as unusually large breasts or small waists) or in a sexually provocative way (i.e. exposed breasts/cleavage/stomachs/midriffs/buttocks). Of course, not just female characters but all characters in games are usually depicted as hypersexualised, yet it is usually only female characters that are depicted as sex objects (Dill et al., 2003; Jenkins, 1998). Given this existing male gendering of games, therefore, designing games specifically with girls in mind would be to adopt the conventional stance within the industry but to apply it to a different user group. Within other media, such as books, television, and films, moreover, female gendering is quite common, with 'chick flicks', 'bodice rippers', romantic comedies and soap operas explicitly marketed for women (Crawford, 2001).

## Hard-Core vs Casual Gamers

Just as with other types of games (such as chess or bridge, and any number of physical sports) some people are devoted to game playing (even to the point of turning professional, see Pedersen, 2002) while others play only occasionally and do not maintain a special commitment to game playing as a lifestyle-defining activity. These two groups of game players (or *gamers*) are known respectively as *hard-core* and *casual* (Ip & Adams, 2002). Because of their different experience with and commitment to game playing, hard-core and casual gamers have different gaming-needs and -desires.

Hard-core gamers tend to be young and male, and to spend much of their spare time engaged in game-related activities. They hunger for game-related information, discuss games with friends and via online bulletin boards, and modify or extend games in a creative way (Ip & Adams, 2002). By contrast, casual players (who come from a wide range of ages and both genders) have limited time for game playing and tend to engage in quick bursts of gameplay before moving on to do something else, and thus for casual gamers a satisfying play experience is one in which they can accomplish something within a short period of time (Laramée, 2001; Mechner, 2000).

Because hard-core gamers allocate more of their time to game playing they prefer deep games that provide a complex and involved gameplay experience and that they can play over many long sessions. Hard-core gamers can tolerate complex game controls and can also tolerate the frustration that arises when learning a new game (Ip & Adams, 2002; Rouse, 2000). By contrast, casual gamers have low tolerance and patience for frustration and need games with clear and simple rules and controls (Crawford, 1992a; Edge, 2002e ; Laramée, 2001; Logg, 2000; Mechner, 2000; Wright, 2000).

Hard-core gamers begin playing games early in life and develop an extensive knowledge of the industry, of technology, and often have the latest high-end (and thus expensive) computers/consoles (Ip & Adams, 2002). They also desire high-end software technology in their games (Game-Research.com, 2002). By contrast, casual gamers don't feel the need to have the latest hardware or to push it to its limits. They will not judge games primarily on the basis of their graphics because they don't have enough experience to compare between products on this basis (Crawford, 1994c). Casual gamers actually prefer low technology because they want something that works first time, that is not expensive and that is easy to use (Game-Research.com, 2002; Laramée, 2001).

Hard-core gamers play for the exhilaration of engaging in competition with themselves, the game, and/or other players, and so long as a game is challenging they will continue to play. By contrast, the casual gamer plays not for the exhilaration of victory but for the joy of playing the game. Casual gamers do not just want a challenge, they want variety. For a game to appeal to a casual gamer it must be different each time they play it (Adams, 2001c; Ip & Adams, 2002; Logg, 2000).

# The Creation of Interactive Entertainment

> [E]ach art is circumscribed by certain economic realities. Film, because it is a very expensive art, is especially susceptible to the distortions caused by economic considerations. (Monaco, 2000, p. 33)

> [O]ne of the biggest differences in opinion about game development focuses on whether a game is an art form or a business venture. Publishers often focus on game profitability and maximizing their revenue, while many developers create games for creative satisfaction, with profit as a secondary consideration (Estanislao et al., 2002, p. 11)

The tension between commerce and culture described in Chapter Two is nowhere more evident than within the world of game development. Game development – even more so than film making – is "especially susceptible to the distortions caused by economic considerations" and these distortions are a source of constant concern to game industry pundits:

- "The games industry is horribly derivative, with many games possessing identical gameplay" (Adams, 2001a).
- "Despite our staggering leaps in technology the game play remains relatively unchanged" (Carson, 2000).
- "The industry produces an enormous number of derivative, unoriginal and licensed titles, it displays a striking lack of innovation, and what innovation there is innovation via technology and not via game design" (Costikyan, 1998b).
- "The industry is showing signs of 'genre paralysis'" (Mechner, 2000).

Three factors in particular are responsible for limiting game innovation, namely, that game technology is always improving, that gameplay is difficult to market, and that game developers are frequently the least powerful players within the industry.

Since their inception, computers have undergone constant and rapid increases in processing speed and memory capacity and, because of these improvements, every year it is possible to create games that both look and feel more realistic than those that preceded them. As a result, players come to expect that each year's games will be more visually impressive than those of the year before and thus each year the standards are raised for the lowest acceptable graphics (Falstein, 1998a; Garneau, 2001; Howland, 2001; Rollings & Morris, 2000). High quality graphics are expensive, however, and thus the demand for 'eyeball candy' has led to the phenomena of *hit games*, games that are extremely expensive to make but that will be profitable because they possess significantly better visual appeal than do their rivals. These big-budget games set the standard for the whole industry such that games that do not possess high production values tend to lose money and as a result the game industry has become a hit driven business wherein a small number of very large and expensive games are the only ones to turn a profit, while most others lose money (Crawford, 2000; Mechner, 2000; Meretzky, 2000; Shelley, 2001). To illustrate this process numerically, while up until 1998 about 2000 interactive entertainment titles had been published annually, typically only around 100 achieved sales of 100,000 or more, which is about the level at which a game creates a reasonable profit (Costikyan, 1998a).

What makes the phenomenon of the hit game particularly deleterious to innovation within the games industry is that it is gameplay – not graphics and sound – that makes games special and different from conventional forms of entertainment such as films and television. Films and television can in fact provide better graphics and sound than can games and thus the viability of the interactive entertainment industry as a whole depends upon games providing innovative gameplay (Adams, 2001a; Brody, 1993; Crawford, 2002). It is unfortunately the case, however, that improvements to the look of a game can much more easily be marketed than can improvements to its gameplay. That is, while game graphics may be depicted on printed material or on a web page, a game's interactivity cannot be properly understood except by experiencing it (Kanev & Sugiyama, 1998; Newman, 2002; Rouse, 2000). Despite the superior importance of interactivity in determining the quality of a game, therefore, it is the look of a game that has the more important effect on sales and thus developers tend to spend much of their time trying to improve the visual appeal of their games using new technology, at the expense of improving the (less marketable) gameplay (Crawford, 1995b ; Rollings & Morris, 2000; Sims, 1998) .

A third factor responsible for limiting game innovation is that game developers are frequently the least powerful players within the industry, and this is largely due to financial factors. In 1999 the average cost of developing a PC game was approximately $US2 million, double what it had been two years earlier and forty times what it had been a decade earlier (Laramée, 1999a), while by 2002 the average price of game development for a low-end console title was between US$3-5 million. Because game development is so expensive, game-developers are usually not able to fund game production solely out of their own pockets but instead must seek financial assistance from game-publishers (Laramée, 1999a). In order to safeguard their investments and minimise risk, game-publishers in turn maintain close observation upon the development of the game projects that they are supporting and they will direct developers away from designing games that have not been proven to be successful in the marketplace, which in practice means discouraging innovation (Costikyan, 1998b; Crawford, 1992b; Logg, 2000; Meretzky, 2000).

From the point-of-view of the game-publisher “the best seller is a form of insurance that some massive new gestalt or pattern has been isolated in the public psyche. It is an oil strike or gold mine that can be depended upon . . .” (McLuhan, 1964, p. 60), and thus it is easier to finance games that are sequels or variations on the familiar patterns set by bestsellers than to finance something new (Logg, 2000; Mechner, 2000). This is so much the case that “publishers are more willing to spend $1 million on a . . . clone than under $100,000 on a promising concept for an original product” (Berry, 1997). While publishing decisions are frequently made on a commercial rather than a creative basis this does not, however, mean that publishers always know best. Some of the most popular games of the last decade (such as *SimCity*, for example) had difficulty getting published because they did not neatly fit within an established genre (Robinett, 2003; Meretzky, 2000; Wright, 2000).

Not only is producing games from already visited patterns desirable from a publisher’s point-of-view, it is also good marketing strategy because experimental and innovative games often lack mass-market appeal and also because users tend to be more confident in purchasing a sequel since they know what they are getting (Edge, 2002b; Rollings &

Morris, 2000). The presence on the market of many nearly identical games means, however, that marketing is all important and because of this marketing costs have risen above game production costs. During the early 1990s there was a standard of one dollar of marketing for one dollar of product, while ten years later marketing cost two or three times as much (Laramée, 1999a).

Not just publishers and marketers, but game distributors too have a great deal of control over the possibility of success of a game.♣ Because their shelf-space is limited and there are many games competing for a place, distributors will quickly remove games that are selling poorly even if they have only been on the shelves for a few weeks. Under such conditions innovative games – which must create a whole new market for themselves – are unlikely to last long. This being said, however, for an innovative game to even get onto the shelves of a major distributor is impressive. Retailers, just like publishers, select games on the basis of their commercial potential rather than creative merit, and an innovative game always has yet to establish its commercial potential (Cassell & Jenkins, 1998; Laramée, 1999a; Mechner, 2000).

Collectively, game publishers, marketers, and distributors are more concerned with issues of presentation than with gameplay and thus tend to discourage innovation and experimentation. Moreover, they eat up most of a game's saleprice: wholesalers and retailers taking 30–60%, and publishers taking 35–40% (Berry, 1997; Crawford, 1996a; IDSA, 2001a). Game design thus tends to be not only a creatively restrained and

♣ In North America the top ten retail chains control approximately 85% of all game sales (Laramée, 1999).

technically difficult enterprise, but also a financially unrewarding one for all but the very few (Crawford, 1991; Falstein, 1998b; Laramée, 1999a; Rouse, 2000).

## Independent Game Design

> What was once a massive undertaking requiring vast investments of capital is now very close to being that personal, flexible instrument of communication that Alexandre Astruc called the 'camera-pen'. (Monaco, 2000, p. 385)

> If film is essentially an economic product, nevertheless there have been numerous filmmakers who have worked without any conceivable regard to the realities of the marketplace and have managed to survive. (Monaco, 2000, p. 231)

> Today, anyone can produce a book, film, record, tape, magazine, or newspaper with less training than it takes to fix a leaky faucet. But can these newly empowered producers of media get their work read, seen, or heard by large numbers of people? So long as the work is specialised and directed to a sharply focused audience, this is no problem. (Monaco, 2000, p. 438)

While in the above passages Monaco is speaking about the creation of films, his words equally apply to the creation of digital games. Not all game design must be constrained by the economic forces described earlier. There does exist the potential for (and to some degree, the actuality of) independent game design, publishing and distribution (Zimmerman, 2002). Independent games differ from mainstream games in that they are: more innovative, aimed at a casual gamers, small in size, quick and cheap to make, created with little pressure from publishers, and able to make a profit by costing less even though they sell less (Chromatic, 2002).

Within the interactive entertainment industry the most successful companies have tended to be those that have released the biggest hits, and these hit games have in turn tended to be games from established genre with excellent graphics. As was noted earlier, however, the creation of a hit game is very expensive and competition amongst hit game contenders is fierce, and thus while potential rewards may be high there are also substantial risks involved (DFC Intelligence, 2000). There is a different path that a game developer can, and indeed must travel, however, if they are small and if they want to create innovative games, and this is the path of creating games for casual gamers. It is mainly the hard-core gamers who desire the most advanced game graphics and thus the lack of such graphics will not necessarily bother casual gamers (Laramée, 1999b). Moreover, casual gamers (who are more likely than hard-core gamers to be women and to be over 35) are less genre-bound than hard-core gamers and are thus potentially more likely to respond to innovative games (Friedman, 2001; Stout, 2002). While innovative games aimed at casual gamers are unlikely to be large sellers, they may potentially be massive sellers since the most successful games are usually those that are truly novel (Costikyan, 1998b). *SimCity* was an example of such an immensely popular innovative game, as was *Tetris*. Such games sell well, not just because they offer interesting new gameplay to existing players, but also because they appeal to people who have not tended to play games before (Jenkins, 2002b).

Because the involvement of publishers within a game-development project tends to reduce innovation, the development of innovative games requires that publishers not be involved (at least, in the early stages), and this in turn requires that games be produced inexpensively. Inexpensive games do not, however, have to be low quality games. Indeed for a number of reasons inexpensive games are more likely to be good games.

First amongst these reasons is that games designed by committees or teams tend to lack the coherence and clarity of games produced by individuals (Crawford, 1994b; Meier, 2000; Rollings & Morris, 2000; Rouse, 2000). Second, games designed by committee tend to be aimed at everybody (and are thus really aimed at nobody), whereas individual game designers create games that they personally think are fun and that will thus at least be fun to other people like them (Crawford, 2000, Meretzky, 2000; Rouse, 2000). Third, low-budget games are inevitably small games, and the need to keep game size to a minimum requires designers to remain focussed on creating interesting gameplay rather than adding nonessential and distracting features. As a result, small games are usually the most replayable games (Adams, 2001c; Vassey, 1999). Fourth and finally, small games are easier than large games to debug and test (Berry, 1997), and thus are less likely to have problems that will detract from their gameplay.

Having produced a low-budget innovative game aimed at casual gamers, distributing it online possesses a number of advantages over physical distribution through retail outlets (Meretzky, 2000). Games distributed online can remain available to be discovered by people over a period of years (unlike a period of weeks on a retailers shelf) (Berry, 1997; Laramée, 1999a; Palumbo, 1998), they can be sold more cheaply than games sold through retailers (who take a large slice of the saleprice) (Laramée, 1999a; Mulligan & Patrovsky, 2003), and they can be constantly and easily improved through implementing the feedback that one receives from players (Berry, 1997). Of course, games distributed online must be small games since for many people (and casual gamers in particular) even 10Mb downloads are too large (Estanislao et al., 2002; Mulligan & Patrovsky, 2003), yet great games can be produced in under 10Mb. For example, when the first nine levels of *Doom* were released as shareware in 1993 they consumed only 2.3Mb, and *Doom* was a massive hit (Turner, 2003).

A number of methods are available for selling games distributed online. One method is to release the game for free and then make money from it some other way, such as through advertising. For casual gamers who are not interested in long and/or complex gameplay, free online games are of particular interest (Estanislao et al., 2002). Another way is to release the game as *shareware*, as a limited version of the game that people are able to play before they decide whether or not to buy it. Because they can play for free many more people will play the game than would have if they had to pay up front, and if even a fraction of a percent of these people then go on to buy the game can still turn a profit. Moreover, those people who do choose to buy will most likely tell their friends about the game and thus market it more effectively than any advertising campaign could. It was indeed this very process that lead to *Doom*'s great commercial success (Turner, 2003).

A concrete example of online game distribution and sales is Shockwave.com:

> **BECOME A SHOCKWAVE.COM GAME DEVELOPER!**
>
> Did you know that most of the amazing games you see on Shockwave.com come from external game developers? Maybe the next one will come from you!
>
> **What are we looking for?**
>
> Games should be easy to learn, but difficult to master. Compelling. Addictive. Clever. Unique. We encourage material with humor, wit

> and attitude, but we do not accept profanity, excessive violence or pornography. The majority of our games are simple, but compelling, puzzle and action games. We strive to present games with production values that set the standard for online gaming.
>
> We deliver gaming experiences to our users through a variety of formats: free online play, downloads for purchase, and subscription use via GameBlast. We prefer games that can be delivered over all of these channels. Usually, a basic version of a game is available for free online play, and a more feature-rich version is available for purchase and subscriber access.
>
> Shockwave.com supports a variety of technologies: Flash, Java, Director-Shockwave, and C++.
>
> In order to start working with Shockwave.com, your game must be complete or nearly complete. Although we are always looking for good ideas, we generally cannot start serious negotiations with a new developer until your game is complete enough for proper evaluation.
>
> Games that are available only for free, browser-based play earn royalties as a portion of the advertising revenue generated by the title. Games with premium versions available earn royalties based on consumer product and subscription revenues instead.
>
> Download games must use our "KeyHole" digital rights management system, which wraps the game in a secure time-limited, and possibly feature-limited, trial mode. Once the trial period has expired, users may purchase an unlock key for permanent ownership or join our GameBlast subscription service to play the game as long as they are active subscribers. Our team generally handles the wrapping – you just send us the complete, unlocked game and we wrap and build installers.[♣]

As is evident from the above quote, Shockwave.com provides a variety of useful services for game developers who wish to distribute and sell their games online, and the Shockwave.com website hosts a large number of games. While those game-developers who distribute and sell their games through Shockwave.com are not entirely

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♣ Retrieved May 10, 2004 from http://www.atomshockwave.com/asw_working_devinfo_games.htm.

independent, their relationship with Shockwave.com is not one that inhibits innovation. Quite the contrary, a site such as Shockwave.com is *offering* innovative gameplay and thus developers are encouraged to develop “unique” games.

## Summary

Games differ from entertainments in that they provide their users with goals and challenges rather than interesting performances, they are interactive and require activity rather than passivity from the user, and they are based upon rules rather than sequences or collections of events.  Two types of interactive entertainments exist.  The data-intensive type is based upon anticipatory systems, possesses a large event/data component, and has the most similarities to conventional entertainment.  By contrast, the process-intensive type is based upon complex-system-simulations, is predominantly rule-based, and is the most interactive and game-like.  Digital games are of this latter type.

Digital games are a mass medium.  In the United States, digital game consoles exist in approximately 30% households, about as many hours per person per year are spent playing games as are spent reading books, and game sales are comparable in magnitude to cinema box office takings.  While game players are predominantly young and male, about 30% are over 35 and the proportion of female gamers is significant and expected to rise over time.

While it is in the nature of digital games to be simulations or simulacra, the systems that digital games usually simulate are not the unfamiliar systems dealt with by scientists. Rather, they are the glamorous and exciting systems that people (and young males in particular) would like to be able to interact with in reality if only these systems were not so dangerous, difficult, or expensive. While many simulation-games do have a science-fiction theme, very few actually incorporate scientific realism, and even fewer are based upon unfamiliar scientific systems. Nonetheless, some of the most popular digital games of all time have been innovative simulation-games, and thus the prospects for this genre are good.

Digital games possess a number of attributes that make them enjoyable to play. They create an alternate reality that operates according to new rules and within which the player may engage in new kinds of behaviours. This reality is immersive, by virtue of its realistic look and feel: its high-quality graphics, sound, and interactivity. This reality behaves in a complex way, exhibits emergent properties, and thus provides a non-trivial and constantly changing challenge to the player. In order to meet this challenge the player must, over many game sessions, experiment with and explore the gameworld and discover how it behaves such that they may control it and eventually win the game. Many games allow players to create modifications and to socialise around the game in various ways, and such attributes are of great interest to hard-core players in particular.

*One wonders sometimes if science will not grind to a stop in an assemblage of walled-in hermits, each mumbling to himself words in a private language that only he can understand.*
*(Boulding, 1956/1991, p. 240)*

CHAPTER FOUR

# Scientific Simulations

In order to support the idea that digital games can make science intrinsically enjoyable it is necessary, amongst other things, to show that there are certain attributes of simulations and games that make them effective in facilitating scientific knowledge-construction. The effectiveness of simulations and games at facilitating scientific knowledge-construction has been most discussed with regards to scientific simulations, educational simulations, and educational games. The overall purpose of this chapter is to discover in what ways scientific simulations may facilitate knowledge construction. This purpose will be realised, however, within a more general discussion of what scientific simulations are, why they are created, who creates them, why they are used, and some of the factors that affect their use.

# What are Scientific Simulations?

To begin with the simplest definitional problem, a scientific simulation is a simulation whose intended users are scientists. What, though, is a simulation? Speaking generally, simulation is a technique whose aim is to imitate the *behaviour* of some target system by means of some other, analogous, system. In the case of scientific simulations the other, analogous system is a mathematical model. A mathematic model is a simplified or idealised representation of a system by means of a set of mathematical (e.g. partial differential, algebraic, integral) equations (Seydel, 1997; Ulrich, Imboden & Schwarzenbach, 1995). The mathematical equations that make up a model represent the various processes thought to take place within the modelled system.

A mathematical model becomes a simulation when the equations that make it up are solved numerically (i.e for varying sets of input values) with the purpose of mimicking the dynamic (time-varying) behaviour of the system (Grant & Thompson, 1997; Ricci & van Doren, 1997; Seydel, 1997). When algorithms forming part of a computer program are used to solve these equations the simulation becomes a computer-based simulation. Under these circumstances the solutions may be represented as tables of numbers, as graphs, or indeed in any other form that is considered useful by the designers and users of the simulation.

All models of systems that scientists are interested in (excepting the most trivial cases) are simplifications of those systems. Reality is simplified into a model in a two main ways. The first way is to select "a portion of the universe around which we draw an imaginary boundary, for the purpose of study of what is enclosed inside this boundary" (Chorafas, 1965, p. 4). The second way is through the selection of assumptions. A system that would ideally be modelled using non-linear equations will, for example, instead be modelled with linear (i.e. more mathematically tractable) equations, or a system may be modelled using fewer variables than it actually has (Seydel, 1997). These two forms of simplification determine the scale and scope of a simulation. Scale refers to the resolution of the model (i.e. how much reality is encompassed), whereas scope refers to the physical complexity of the model (Sameh et al., 1996). As an example of the difference between scale and scope, models of human neural processing are usually based around only a few layers of simulated neurons rather than the billions that make up the brain (a scale issue), and these neurons relate to each other in much simpler ways than do actual neurons (a scope issue) (cf. Rumelhart, Hinton & McClelland, 1986; Crick & Asanuma, 1986). The mix of assumptions and boundaries defining a model determine how difficult (i.e. possible or time-consuming) its equations are to solve and how well it approximates reality (Seydel, 1997). The issue of how difficult a model's equations are to solve is a crucial one in simulation because any computer, no matter how powerful, can always be assigned problems that are too difficult for it to solve, and scientists are always wanting to solve more complex problems than current computing technology is capable of solving.

Any given mathematical model may be assigned to one of three classes: discrete, continuous and hybrid (containing both continuous and discrete elements (Hlupic & Paul, 1996; Music & Matko, 1999). In a discrete model, space, time, and the features of the system can have only a finite number of states, as opposed to an infinite number of possible states in a continuous model. Moreover, while continuous models represent the relations between macro-features of the system, discrete models represent the structure and dynamics of the discrete entities that make up the system (Lorek & Sonnenshein, 1999). In discrete modelling the aim is to let the behavioural complexity of a system emerge from simple rules, from the elementary dynamics of its interacting parts, rather than modelling from a global point-of-view (Talia & Sloot, 1999). Discrete models can capture the peculiar features of systems that evolve according to the local interactions of their constituent parts, and thus this form of modelling may be considered a *bottom-up* approach, whereas continuous modelling is a *top-down* approach (Lorek & Sonnenshein, 1999). Discrete models are particularly effective for modelling complex systems within which global behaviour is determined by the behaviours of many simple interacting elements, such as is the case in fluids, genetics, road traffic flow, economics, and the weather (Cannataro et al., 1995; Talia & Sloot, 1999). One of the chief benefits of discrete models is that they offer a modelling solution when it is difficult to generate equations for the system as a whole, as is the case, for example, when attempting to model the effects of global warming on the geographical distribution and population dynamics of species (Karafyllidis, 1998).

## Why Design Scientific Simulations?

The primary goal of science is to produce simple models that can explain, reproduce, and predict the complex behaviours found in nature (Talia & Sloot, 1999) and the great early success stories of science – the laws of classical and celestial mechanics devised by Kepler, Galileo and Newton – were famous both because of their simplicity and because of their explanatory power. As Weinberg (1972/1991) notes, however, mechanics is only "the study of those systems for which the approximations of mechanics work successfully" (p. 502). That is, while the great historical successes of theoretical science have typically revolved around finding mathematical formulae whose use can predict the future behaviour of some system, it has in fact been possible to generate such formulae only for systems with unusually simple behaviour (Wolfram, 2002), and it has thus been these systems that scientists have focused their attention on. So for example, when Charles Sherrington began studying the spinal cord in the late 19th century, he isolated the stretch reflex, "a small portion of the whole, simple within itself and capable of being studied in functional isolation" (Ashby, 1958/1991, p. 249). Thus, despite the fact that complex systems are by far the most numerous systems with which we come into contact (Seydel, 1997; Watson, 2002), and that significant problems are seldom capable of being reduced to simple models (Weaver, 1948/1991), science has by and large ignored complex systems in favour of studying and describing those few simple systems that its methods are capable of dealing with (Chorafas, 1965; Pantin, 1968).

Weaver (1948/1991) divided the problems that scientists have attempted to solve into three groups: problems of simplicity, problems of *disorganised* complexity and problems of *organised* complexity. Problems of simplicity are those with which the physical sciences before 1900 were largely concerned. They are typified by *two-variable* problems: problem situations wherein it is possible to hold constant all but two variables in the system. So for example, holding mass constant one can explore the relationship between force and acceleration, holding resistance constant one can explore the relationship between voltage and current, and so on.

Problems of *disorganised* complexity are those that became mathematically tractable with the advent of probability theory. They concern situations, such as the behaviour of gases, where nothing can be known about each individual component of the system but, because there are so many of them acting randomly, quite precise knowledge can be gained about their behaviour *en masse*. Problems of *organized* complexity cannot be understood in this way, however, because although they concern systems composed of a large number of elements, these elements are organized and interact with each other in structured (and thus non-random) ways. It is these systems, that are both complex and organized, that are generally referred to as *complex systems*.

The characteristic of complex systems that has made them so difficult for scientists to study is that they exhibit *emergent* properties, meaning that their complex behaviour emerges unexpectedly from the interactions of what are often very simple parts (Wolfram, 2002). So for example Checkland (1976/1991) notes that "in physics and physical-chemistry there are phenomena – such as those connected with heat flow – which have *no meaning at all* in terms of individual atoms and molecules", and that "Such *emergent properties* are characteristic of a given level of complexity" (p. 264). It is this phenomenon of emergence that necessitates the existence of a variety of sciences (i.e. physics, chemistry, biology, psychology) because, while all biological entities (for example) obey physical and chemical laws, they also obey additional laws (i.e. emergent laws) that are not specified within physics and chemistry (cf. Peacocke, 1971).

Emergent behaviour presents a problem for science because traditionally science has been an *analytic* and *reductionist* endeavour (Checkland, 1976/1991):

> In the existing sciences much of the emphasis over the past century or so has been on breaking systems down to find their underlying parts, then trying to analyse these parts in as much detail as possible. . . . But just how these components act together to produce even some of the most obvious features of the overall behaviour we see has in the past remained an almost complete mystery. (Wolfram, 2002, p. 3)

Synthesis – the assembly of parts into a functional whole – has historically been made to work only when studying systems whose component parts engage in few and linear interactions because the equations used to model such interactions may be solved algebraically (Ashby, 1958/1991). It is in the nature of complex systems, however, that the relationships amongst their components are best modelled using non-linear equations, and in order to predict the future behaviour of a system using a set of non-linear equations one must solve the entire set of these equations numerically for each instance in time between now and the future time to be predicted, a process potentially involving a massive computational effort (Wolfram, 2002). For this reason, complex phenomena could be investigated only qualitatively until modern computational abilities became available (Cannataro et al., 1995; Weaver, 1948/1991).

The fifty years since the birth of the computer[♣], and especially the last decade, has seen the rise of a new *synthetic* and *computational* science based upon the use of simulations (Spezzano & Talia, 1999). With the advent of digital computers, and as the speed and memory capacity of these machines has increased, systems of equations that were previously too time-consuming to solve have now become soluble, and systems that could previously only be pulled apart can now be put back together again. This process (i.e. simulation) is not reductionist but is instead *constructionist*: it creates models that exhibit much of the complexity of the real systems that they represent (Rumble, 1998).

Because the use of simulations allows scientists to engage in research that was previously impossible, computational science is increasingly being considered as a discipline in its own right (Fishwick, 1995): as a fundamental scientific approach naturally complementing analysis (Voit, 2002), and as a third component of the scientific method, equal in importance to experiment and theory (McCurdy et al., 2002). The separateness of computational science from traditional science is demonstrated in three main ways. First, as described above, computational science is a synthetic, constructive science as opposed to an analytic, reductive science. Second, computational science is a multidisciplinary as opposed to a sub-disciplinary science (McCurdy et al., 2002; Talia & Sloot, 1999; Thomaseth, 2001). The normal practice of science involves the creation of sub-disciplines because the process of analysis uncovers new entities capable of being studied in their own right. Computational science, by

[♣] Macedonia (2001) notes that "Simulation and computing are linked like two strands of DNA into a common heritage and future" (p. 290). The earliest computers, such as the ENIAC, were created in order to carry out simulations and the need to carry out larger and more detailed simulations has been a constant driving force for the development of computer hardware and software.

contrast, involves exactly the opposite process – the integration of different disciplines and the integration and synthesis of findings from a variety of areas (Pugh & Johnson, 1999). Third and finally, computational science differs from analytic science in terms of the real-world relevance of the problems that it seeks to solve. That is, while the analytic process of conventional science involves studying systems that are increasingly esoteric and distant from day-to-day life, the synthetic process of computational science does exactly the opposite – it brings science back towards studying systems with which non-specialists are familiar and towards solving problems with which non-specialists must deal (Checkland, 1976/1991).

## Who Designs Scientific Simulations

Computational science involves collaboration between natural scientists and computer scientists – or at least requires researchers who are skilled in both areas – because software systems for scientific computing are complex and are becoming increasingly so as computers themselves grow in complexity (Joshi, Drashansky, Rice, Weerawarana & Houstis, 1997). As a result of these collaborations a variety of software tools has become available to assist the scientist in their simulation work, so that while simulations can be programmed from scratch using a general-purpose programming language they can also be created using simulation languages, simulation tools, or purchased 'off-the-shelf' (Hlupic & Paul, 1996; Lorek & Sonnenshein, 1999; Ulrich et al., 1995).

*Off-the-shelf* simulators allow users to specify values for various parameters of their model but do not allow them to create their own mathematical models (cf. Vibert, Pakdaman, Boussard & Av-Ron, 1997), and thus while they are quite user-friendly and accessible to nonexperts their ability to simulate systems of interest is somewhat restricted (Hou & Xu, 2001). *Simulation tools*, in contrast, allow users to formulate their own mathematical models and will then solve the equations of these models using appropriate algorithms. Simulation tools are usually domain-specific and thus cannot be used to simulate any conceivable complex system, but they are more flexible than off-the-shelf simulators and require less expertise to use (Elmqvist, Mattsson & Otter, 2001). When the conceptual gap between the system to be modelled and the tools available to model it (i.e. the *modelling gap* – Lorek & Sonnenshein, 1999; Elmqvist et al., 2001) is too large, then a scientist will have to develop a completely new simulation using a general-purpose simulation language, though this option is only available to scientists with considerable programming experience. It is of course possible to program a simulation truly from scratch using an everyday programming language such as C, Java, or Visual Basic, and this in fact is what scientists mostly had to do up until the late 1970s when simulation languages and tools started becoming more widely available (Dogramaci & Adam, 1979). Simulation languages are superior to ordinary programming languages, however, in that they provide functionality such as time control, set manipulation, statistics gathering and reporting, data visualisation and software libraries, all of which are of particular use to modellers and which ordinary programming languages will not provide (Adam & Dogramaci, 1979; Lorek & Sonnenshein, 1999; Spezzano & Talia, 1999).

While the use of general simulation languages and ordinary programming languages does provide great flexibility, this flexibility does come at a cost, being that a large amount of system analysis and programming must be undertaken before any actual science can be engaged in using the simulation (Dogramaci & Adam, 1979; Elmqvist et al., 2001). Moreover, when simulations are designed from scratch the models embedded within them are difficult to communicate to other scientists because the scientific model and all of the other software required to run it are mixed together (Lorek & Sonnenshein, 1999). Additionally, because professional scientists are not usually trained programmers their code can be badly written, slow, and full of errors, and this in turn can make it difficult to determine to what degree the output of the simulation represents the underlying model and to what degree it is simply an artefact of poor programming. Perhaps because of these difficulties surveys of simulation software users have found that a majority of respondents used simulators rather than simulation languages, and from one third to one half used both (Hlupic, 1999).

## Designing a Simulation

Mathematical model building, propose Naylor, Balintfy, Burdick and Chu (1966), "is an art and not science" (p. 29), and the same thing may be said of simulation design. While each of the tools and techniques used in simulation design is of a scientific nature, their usage to describe real world systems involves experience-based decisions on the part of the modeller. Since only some of a system's attributes and relationships may be incorporated into a simulation, those that are easiest to measure and that exert the greatest effect on the process are most likely to be chosen (Wenli et al., 2000). Moreover, all models must possess boundaries and simplifying assumptions and these must be chosen on the basis of the needs of the simulation user, as well as on the basis of the hardware, software, and algorithms at their disposal. Because of the great degree of latitude that the simulation designer thus has regarding the choices that they make in these regards, simulation building is a fundamentally creative act.

The process of designing and building a simulation is a cyclic one, and four main stages may be identified within it (Grant & Thompson, 1997; Fishwick, 1995; Talia & Sloot, 1999):

1. Conceptual model formation and design

During this stage the system's components, borders, and its key relationships must be established (Covert et al., 2001). The modeller must also decide upon the model's structure (discrete, continuous, or hybrid), and its scale and scope (Dogramaci & Adam, 1979).

2. Quantitative model specification

During this stage, the mathematical equations needed to model the system must be specified. These equations must then be converted to algorithms to run within a computer program (Mattson & Elmqvist, 1997).

3. Model execution and evaluation

During this stage the simulation is run and its performance is compared with that of the real world system. The simulation should be able to produce the same sorts of data and input/output relationships that were initially gathered. To the degree that the simulation can accurately reproduce the real world data it is a valid model (Dogramaci & Adam, 1979). A variety of factors can conspire to make a simulation invalid quite apart from its underlying equations being inaccurate: factors including errors in input data, errors in programming, and constraints and idiosyncrasies of the programming language.

4. Model use

Once the simulation has finally been completed it may be used as part of ongoing empirical research. This research will inevitably reveal inadequacies of the model, so provoking model revision, and perhaps ultimately the development of an entirely new model.

## Using Scientific Simulations

Fundamentally, the role of a scientific simulation is to act as a virtual laboratory (Talia & Sloot, 1999), yet given this overarching role simulation tends to play one of three different subsidiary roles within scientific research, namely, as (1) a complement to empirical investigation, (2) a method of investigation superior to empirical investigation, and (3) the only means by which investigation may be accomplished.

### 1. Complementary to Empirical Investigation

Simulations are seen as a complement to empirical investigation (i.e. direct investigation, via experiment or observation, of the natural world) when such investigation is possible but simulation has something extra to offer over and above what is offered by empirical investigation alone. There are numerous complementary benefits offered by simulation:

### (a) Complex Systems

Easily the most important reason why scientists make use of simulations in their work is so that they may investigate, explore, understand, identify important aspects of, and describe the behaviour of complex systems (Fishwick, 1995; Grant & Thompson, 1997; Pykh, Kennedy & Grant, 2000; Talia & Sloot, 1999; Wiechert, 2002). There *are* methods of modelling complex systems that do not involve simulation, and that instead involve the solution of systems of linear equations. When a system is best described using many variables, when variables strongly interact, when the relationships between variables are nonlinear, and/or when a model contains random variables, however, then under these circumstances simulation is the method of choice (Fishwick, 1995; Naylor et al., 1966).

Below in Table 3 is a (by no means exhaustive) list of complex systems/problems that have been investigated using simulations:

**TABLE 3** – A sample of complex systems that have been modelled using simulations.

| | |
|---|---|
| Ecosystems<br>Pykh et al, 2000 | The Cardiovascular System<br>Li, Bai, Cui & Wang, 2002 |
| Natural Resource Systems<br>Grant & Thompson, 1997 | Colloidal Systems<br>Puertas, Fernández-Barbero & de las Nieves, 2001 |
| Transport of Gas Molecules Through Polymer Membranes<br>Tocci, Bellacchio, Russo & Drioli, 2002 | Perceptual and Cognitive Systems<br>Sporns, Tonomi & Edelman, 2000 |
| Cell Physiology<br>Covert et al. 2001 | Early Sensori-Motor Development<br>van Heijst, Touwen & Vos, 1999 |
| Inhomogeneous Physical Materials (liquids, glasses, polymers)<br>Medvedev, 2002 | Plant Growth<br>Pan, Hesketh & Huck,.2000 |

| | |
|---|---|
| The Thermal, Air, Acoustic, and Visual Quality of Buildings<br>Hien, Poh & Feriadi, 2000 | Early Development of the Cerebral Cortex<br>Ryder, Bullard, Hone, Olmstead & Ward, 1999 |
| Air Mass Circulation<br>Martilli & Graziani, 1998 | The Immune System<br>Bernaschi & Castiglione, 2001 |
| Gene Networks<br>Kastner, Solomon & Fraser, 2002 | Lung Airway Structures<br>Spencer, Schroeter & Martonen, 2001 |
| Organism Distribution and Population Dynamics<br>Karafyllidis, 1998 | Biological Membranes<br>Scott, 2002 |

### (b) Integrate Disparate Findings/Understand System Holistically

The process of creating a simulation requires integration of data from all of those areas of study concerned with the components of the simulated system (Elmqvist et al., 2001; Früh & Kurth, 1999; Grant & Thompson, 1997; Ryder et al., 1999, cf. Galison, 1996). In order to simulate the behaviour of a living cell, for example, one must integrate what is known about cell membranes, how cells divide, the various organelles that exist within a cell, and the cell nucleus (amongst many other things). This process of integration is not simply a necessity, however, it is in fact a positive benefit since it provides a means of organization for both storing and later presenting information regarding the system (Kastner et al., 2002; Wiechert, 2002). The process of integration also enables an holistic understanding of the system under study (Grant & Thompson, 1997; Pykh et al., 2000). One particularly important advantage of using simulations as research tools is that it is possible for many different research teams to use exactly the same simulation (Elber, 1996), and thus to be able to directly compare their results.

### (c) As a Theory or Hypothesis, as a Means of Testing Hypotheses and Making Predictions

A simulation is more than simply an embodiment of the current understanding of a given system since the process of creating a simulation requires more information than is usually available. As a result, a simulation is in fact a theoretical synthesis of empirical observations (Fishwick, 1995; Früh & Kurth, 1999): it is a theory in its own right, or at least, an hypothesis. Moreover, just like theories and hypotheses, simulations can be used as means of generating specific questions and predictions regarding a system that can then be tested using experimental data (Dogramaci & Adam, 1979; Nawa, Shimohara & Katai, 2002; Ryder et al., 1999). Once a simulation has been validated against real-world data it can be used to predict the outcome of future experiments (Wiechert, 2002) and to provide a quantitative basis for planning and forecasting (Chorafas, 1965).

### (d) Used to Calculate the Properties of a System Under Study

A tremendous advantage of *in silico* research using simulations over *in vivo* research is that the measurement of systemic properties, such as an estimation of the length of a polymer chain (Tanaka, Iwata & Kuzuu, 2000) or the calculation of the light intensity in various parts of a plant canopy (Hanaan, Prusinkiewicz, Zalucki & Skirvin, 2002), is usually much easier using a simulation because the simulation can be designed specifically to produce the required data upon request (Elber, 1996; Hansson, Oostenbrink & van Gunsteren, 2002).

### (e) Allows Comparison With/Helps Interpretation of Experimental Data/Observations of the System Under Study

The relationship between a simulation (as theory) and experimental data is just the same as with theories in general in that a simulation's predictions are compared with *in vivo* experimental or observational data in order to decide how correct the simulation is (Anderson & Neuhauser, 2002; Borstein et al., 1997; Elber, 1996; Høyrup, Jørgensen & Mouritsen, 2002; Martilli & Graziani, 1998). If the predictions made by a simulation are not accurate it will need to be altered so as to incorporate the new results (Kastner et al, 2002). If, on the other hand, the simulation's predictions do turn out to be accurate then it may be used to check and validate new experimental data (Pykh et al., 2000), and it can thus act as an interpretational tool (Ryder et al., 1999; Wiechert, 2002). Additionally, because simulations are both theories about how the world is and also a replacement for the world itself and capable of producing experimental results, they are also capable of helping to resolve disagreements between various theories and experimental data (Chacín, Vázquez & Müller, 1999; Elber, 1996). Simulations, theory, and experiment thus stand as a triad of research tools that all complement each other (Apollonio, D'Inzeo & Tarricone, 1998; McCurdy et al., 2002; Reilly, 2002).

### (f) Visualisation and Interactivity

The earliest simulations, just like the earliest computers, provided users with neither real-time interactivity nor graphical displays. Users would input parameter values for their model and after some delay would receive back a different set of values that were the model outputs. When visualisation of data first because possible this process still occurred without real-time interactivity, and involved what was called the *post-processing cycle* wherein researchers would input data to the simulation, the simulation would be run, its outputs would then be processed and finally represented graphically (Merimaa, Perondi & Kaski, 2000). This separation of simulation, visualisation and analysis presented serious obstacles to the researcher interpreting the results, and also meant that model errors could only be discovered during post-processing (Huang, 2003).

Much superior to this state of affairs is visual-interactive-simulation (VIS), which involves the combination of a graphical user-interface and the ability to engage in interactive work during both simulation model building and during simulation runs. Because users can both visualise and interact with the model during execution they can interrupt it if it is behaving unexpectedly and it is thus much easier for them to detect and localise logical errors, to validate the results and to perform data analysis (Ceric, 1997; Huang, 2003; Kuljis, Paul & Chen, 2001). Most importantly from a scientific point-of-view, however, VIS allows users to both visually comprehend and interact with invisible, abstract and complex phenomena and systems. Because people possess the innate ability to process graphic information (as opposed to symbolic information), VIS allows large amounts of information to be communicated in a short time and also allows users to identify patterns in data that would not be apparent when represented symbolically. Also, because users are able to alter the behaviour of the simulation and interact with the simulated system in real time they can gain insights into its dynamics in a way impossible before, and as a result their discovery and comprehension of phenomena is greatly enhanced (Huang, 2003; Kuljis et al., 2001; Rohrer, 2000).

## (g) Qualitative Understanding

Visualisation and interactivity together allow researchers to gain a qualitative understanding – or 'feel' – for the target system (Elber, 1996; Hansson et al., 2002; Kofke & Mihalick, 2002; Wiechert, 2002): to gain insights into the relationships amongst variables (Dogramaci & Adam, 1979; Seydel, 1997) and the way that the dynamic behaviour of the system is altered when forces are applied to it (Monserrat, Meier, Alcaniz, Chinesta & Juan, 2001). These insights offered by a simulation (and obtainable without the necessity of dealing with mathematical equations) are at least as important as its predictions (Sigmund, 1993).

## (h) Structure/Function

A particularly valuable type of qualitative understanding that simulations can provide is of the relationship between the structure of a system and the way that it functions or behaves. A simulation can reveal, for example, how the vascular structure of a tree relates to the flow of sap within it (Früh & Kurth, 1999), how individual level behaviours and interactions within an economic system lead to the emergence of aggregate behaviours within the system as a whole (Nawa et al., 2002), how atomic level structures determine the properties of various physical materials (Lupo, Wang, McKenney, Pachter & Mattson, 2002), and also how protein sequences determine the folding of protein molecules (Duan & Kollman, 1998).

## 2. Superior to Empirical Investigation

Simulation has been seen by many researchers as superior to experiment or direct observation of the system under study. As Wiechert (2002) notes:

> For technical systems, the routine application of modelling and simulation software is already state-of-the-art. In certain fields, e.g. the design of analog electrical circuits, these tools have already reached a state of maturity that makes experiments and physical prototype development superfluous. (p. 37)

There are a number of ways in which simulations can prove superior to experiments or direct observations; through (a) allowing more control, (b) allowing more detailed investigation, (c) being cheaper, (d) being less hazardous, (e) being more rapid.

### (a) Increased Control

In a variety of ways, using simulations can allow researchers more control over the way they conduct investigations than is possible *in vivo*. For example, Früh & Kurth (1999) describe a simulation of the hydraulic network of trees that allows them to treat tree architecture as an independent variable, a possibility that normally does not exist. Similarly, using artificial economic agents instead of actual people in economics research is advantageous because more agents can be used, the simulated environments may be run more often than is practically possible with human participants, and the way the agents communicate with each other may be controlled precisely (Duffy, 2001). Similarly again, when using a simulation to investigate hypothesised molecular interactions researchers are able to add and remove molecular connections and to explore the consequences of these changes to the network of molecules: a level of control not possible *in vivo* (Kastner et al., 2002).

Two areas where control is particularly an issue lie in dealing with complex systems and in situations where reproducibility is required (Vemuri, 1978). As an example of the control afforded by simulations when dealing with complex systems, it is difficult to study a living organism's circulatory system because interfering with blood flow can cause the organism to die. When using simulations, however, it is possible to casually alter the functioning of a system without concern for organismic wellbeing. Reproducibility is an issue within science both because of the effect of chance events upon experiments and also because many interesting but unusual events occur spontaneously in nature and outside experimental control. So for example, 'once-in-one-hundred-years' floods, fires, or droughts may be studied using simulations but not often without them.

### (b) More Detailed Investigation

One of the tremendous strengths of simulations as scientific tools is that discrete questions may be asked of them. "Whereas, experimentally, observation is an inevitable convolution of many different factors, we can, with simulation, often isolate one parameter and probe selectively its influence upon the whole" (Andzelm et al., 1999, p. 452). In a similar vein, Kastner et al. (2002) note that their simulation allows them "to track in detail the behaviour of each component of a biochemical pathway", and thus "to delve deeper into the components and ask more complicated questions about the nature of the interactions" (p. 122-128).

### (c) Less Expensive

Experiments and direct investigations can be expensive for a variety of reasons, such as that they are technically difficult to carry out, that they involve dangerous materials and/or environments, or that they are simply laborious. A general benefit of simulation is thus that it can be less expensive than experiment or direct investigation (Andzelm et al., 1999; Barsamian & Hassan, 1997; Hien et al., 2000; Lynn & DuQuesnay, 2002; Naylor et al., 1966; Tocci et al., 2002; Vemuri, 1978). Moreover, because once a simulation has been set up it can be run many times under varying conditions at little extra cost per run, the use of simulations can save expense well into the future (Thomke, 1998). Thus, using a simulation to understand the aerodynamics of a particular wing shape is much cheaper than building an actual aeroplane (or a number of aeroplanes) for testing purposes, while similarly, using a simulation to predict the existence of fatigue and cracks in aircraft structures is cheaper and less time consuming than many direct inspections (Lynn & DuQuesnay, 2002).

### (d) Less Hazardous

Research can involve hazardous substances such as acids, flammable liquids, and radioactive materials (Barsamian & Hassan, 1997; Li, Kildsig & Park, 1997), can involve hazardous situations such as bushfires (Hanson et al., 2000), or can be hazardous to the participants involved, as is the case with medical research (Spencer et al., 2001). Simulation use can allow researchers to avoid hazard (to both themselves and others) and can also allow the study of dangerous situations (such as oil spills, vehicular collisions, and explosions) without actually creating them.

### (e) More Rapid

Simulations can provide answers to research questions more rapidly than can experiments (Andzelm et al., 1999). Especially in applied areas, such as pharmaceutical research, using simulations makes the process of discovery much faster than physical testing is capable of, and this in turn can reduce costs (Grass & Sinko, 2002). Simulation use can also allow the avoidance of trial and error testing and time consuming measuring and field testing (Hien et al., 2000; Llobet et al., 2001).

## 3. The Only Way that Empirical Investigation may be Accomplished

There are a variety of reasons why experiment or direct investigation may not be possible. These have to do with ethical and safety concerns, extreme time scales/spatial scales and environments, and they also have to do with objects under study being not sufficiently controllable to allow for systematic investigation and repeatable experiments.

### (a) Ethical/Safety Concerns

In all branches of science there are researchers who would like to find something out but who cannot do so directly for fear of harming some other person or persons. So for example, researchers studying the cardiovascular system might ideally like to know various bloodflow parameter values but cannot measure them directly because of the invasive nature of the process of measurement (Li et al., 2002). Likewise, studying early neural development in humans is ethically problematic, even using non-invasive methods, simply because any unnecessary risk to a child *in utero* will tend to be seen as too great by both parents and society in general (van Heijst et al., 1999). Likewise again, nuclear war may not be studied directly because no one would wish a nuclear war to be started simply so that it might be studied (Vemuri, 1978). In all such contexts simulations may prove of benefit.

### (b) Time Scales

Sometimes experiments or investigations are not possible because of the time scales involved yet by using simulation, researchers can study dynamic systems in real time, compressed time, or expanded time (Naylor et al., 1966). The ability to expand time can be useful when studying fast moving processes such as bushfires (Hanson et al., 2000), interactions between sub-atomic particles, and car crashes. When deliberately crashing cars for experimental purposes it can, for example, be difficult to observe important details, even when using cameras and instruments, yet with a computer simulation one can zoom in on any area of the car structure that one wishes and play the simulation at an ideal rate (Thomke, 1998). The ability to compress time can be useful when studying slow moving processes like tree growth. The management of tree retention strategies within forests so as to ensure sufficient hollow trees as nests and dwelling places for wildlife is difficult because "The long-term dynamics of hollows in a forest stand are considerably longer than the careers of professional foresters and wildlife managers" (Ball, Lindenmayer & Possingham, 1999, p. 180). When using simulations, however, foresters can straightforwardly comprehend these slow moving systems and can experiment with different tree retention strategies.

### (c) Spatial Scales

Not only time scales but also spatial scales can restrict investigations. When studying with large scale objects such as ecosystems, for example, the only possibility for experimentation lies with simulation (Pykh et al., 2000). Conversely, small spatial scales, such as those involved when studying the diffusion of gas molecules through a membrane, can also limit opportunities for observation, and here again simulations can be of assistance (Li et al., 1997; Tocci et al., 2002).

### (d) Extreme Environments

Investigating the behaviour of substances in extreme conditions, such as high temperature and pressure situations (Chacín et al., 1999), can be problematic for a variety of reasons, not least because measurement instrumentation can be adversely affected by such conditions. When using simulations, however, problems of measurement of this type do not exist.

## Factors Affecting Simulation Use in Science

Given this array of advantages that simulation use provides to researchers one might imagine that simulation would have become the norm throughout science. There are, however, objective factors that determine the possibility of using simulations for any given purpose.

### (a) Hardware Development

Amongst all of the factors that have affected the uptake of simulation use within the sciences, improvements to computer hardware stand as by far the most often referred to by scientists (cf. Andzelm et al., 1999; Joshi et al., 1997; Li et al., 1997, 2002; Martilli & Graziani, 1998; Scott, 2002; Seydel, 1997; Tocci et al., 2002). Not just improvements in speed *per se*, but also improvements in speed based upon the development of parallel processing (Cummings, 1998; Lupo et al., 2002; Spezzano & Talia, 1999; Talia & Sloot, 1999), and even hardware purpose built for performing specific scientific calculations is mentioned (Barsamian & Hassan, 1997; Hansson et al., 2002). Mention too is made of affordablilty (Andzelm et al., 1999; Li et al., 1997) although this is just a reciprocal issue to that of speed.

Schlick (2001) notes that the popularity of molecular-dynamics simulations would be overwhelming if their computational demands were not so great, and hence their scope was not so limited for large systems. The relationship between scope (i.e. how realistic a model is) and computational time is mentioned frequently as a problem: e.g. “a small increase in complexity leads to enormous overhead times in computations” and thus “a compromise between simplicity and detail must be achieved” (Chacín et al., 1999, p. 5). As the size, duration and complexity of a simulation increase, so too does its computational expense and running time (Ilnytskyi & Wilson, 2001), and while reducing the scope of models makes them computationally cheaper, such simplified models then miss out on important details (Elber, 1996; Tanaka et al., 2000). Physical and temporal scale can also be important factors affecting computational time. When studying some types of system simulations must be large in scale because these systems demonstrate large scale effects (Medvedev, 2002). Additionally, systems may demonstrate effects on both short and long time scales (requiring many small-time-scale calculations to be made before long-time-scale effects can be calculated)(Berne & Straub, 1997; Elber, 1996), and they may have to run for sufficient time for certain properties to be calculated or for certain interesting behaviours to be observed (Daggett, 2000; Hansson et al., 2002).

To gain some perspective on the relationship between model complexity and computational time it is enlightening to consider that in 1998 it took researchers at the Department of Pharmaceutical Chemistry, University of California, San Francisco, four months of dedicated CPU time on a 256 processor Cray T3E super-computer to simulate for only one microsecond the folding of a protein fragment (Duan & Kollman, 1998; Schlick, 2001). Even small improvements to speed or simplifications to a model can thus exert a profound affect upon the rate of research.

### (b) Algorithm Development

While improvements to computer hardware over the last two decades are well known to most people, "people are much less familiar with the enormous increase in algorithmic power over the past 60 years." (Houstis & Rice, 2000, p. 243). Houstis and Rice note, for example, that "the algorithms for multiplying two ten-digit numbers have been sped up by a factor of perhaps 100" (p. 244). When one considers that a single algorithm may be used thousands of times a second within a given simulation it becomes easier to understand why knowledge of how to code one's simulation most efficiently can mean the difference between success and failure (Edge, 2002a). Improvements to algorithms are listed as an important factor in improving scientific work with simulations by a number of researchers (Andzelm et al., 1999; Bernaschi & Castiglione, 2001; Elber, 1996; Martilli & Graziani, 1998; Schlick, 2001; Seydel, 1997; Talia & Sloot, 1999).

### (c) Software Development

Because the absence of high-level languages forces researchers who wish to use simulations to begin programming from a low level (even at the level of an individual machine in the case of unique parallel processing computers), and because most natural scientists are not also computer scientists, software support for simulation is vital for its development (Spezzano & Talia, 1999).

### (d) Theory Development

While hardware, software, and algorithms are all important to simulation design, if scientists did not possess enough understanding of a system to model it mathematically then simulation would not be possible at all. Limitations to theory are always a problem for researchers because it is not possible to know, when dealing with a complex system, to what degree particular system behaviours are an artefact of the questionable assumptions that the researcher has made and to what degree they derive from aspects of the model with which the researcher is confident (Anderson & Neuhauser, 2002). Improvements to theory are thus mentioned by a number of researchers as an important factor in increased use of simulations in their area (Andzelm et al., 1999; Martilli & Graziani, 1998; Tocci et al., 2002; van Heijst et al., 1999).

### (e) The Multidisciplinary Nature of Simulation Design

Ineffective communication amongst scientists from different domains is seen by some as a significant obstacle to interdisciplinary modelling (Grant & Thompson, 1997). While some researchers note an increase in inter-disciplinary cooperation (Nawa et al., 2002; Scott, 2002), barriers to cross-disciplinary work are deeply embedded within the structure of academic institutions and it is thus within applied scientific disciplines such as engineering that multidisciplinary simulation use is most prevalent.

## Summary

In order to support the idea that digital games can make science intrinsically enjoyable it is necessary, amongst other things, to show that there are certain attributes of simulations and games that make them effective in facilitating scientific knowledge-construction, and this chapter has revealed a number of attributes of scientific simulations that facilitate knowledge construction. First, scientific simulations are able to stand-in for or re-create reality and thus allow researchers to investigate things that would normally be difficult or impossible for reasons of expense, hazard, ethics, or physical and technical constraints of various kinds. Second, simulations enable researchers to study complex systems, systems that previously were beyond the reach of scientific investigation. Third, simulations allow researchers to visualise and interact with the systems that they study and can thus provide them with the ability to: comprehend these systems in new and valuable ways, perceive the relationship between the structure and function of these systems, and to gain a qualitative understanding of these systems.. Finally, simulations can act as a new form of scientific tool, allowing the synthesis of research findings, the generation and testing of predictions, and the calculation of system properties.

*Ultimately, no one can extract from things, books included, more than he already knows. What one has no access to through experience one has no ear for. Now let us imagine an extreme case: that a book speaks of nothing but events which lie outside the possibility of general or even of rare experience – that it is the* first *language for a new range of experiences. In this case simply nothing will be heard . . .*

*(Nietzsche, 1888/1977, p. 22)*

CHAPTER FIVE

# Educational Simulations

Following on from the previous chapter, the purpose of this chapter is to discover what attributes of *educational* simulations facilitate the construction of scientific knowledge. As we shall see, simulations are used by educators for many of the same reasons that they are used by scientists. Scientists, however, use simulations within a *communicational* context to facilitate *their own* knowledge construction, whereas educators use simulations within an *educational* context to facilitate the knowledge construction of their *students*, and thus the issue of *educational effectiveness* arises in the latter situation but not in the former. In other words, whereas scientists may judge for themselves how beneficial simulation use is, the issue must be studied empirically when it comes to students. This chapter will thus explore not only what educational simulations are and why they are used, but it will also discuss some of the research dealing with their effectiveness.

## What is an Educational Simulation?

Because scientific simulations are created to facilitate learning on the part of experts they are too complex and too time-consuming to be of use in educational contexts (Warner, Catterall, Gregory & Lipson, 2000). Educational simulations (also known as *computer-assisted learning packages* (Elton, Lewis & McKenzie, 1978)), which are created in order to facilitate learning on the part of novices, are neither as complex nor as realistic as scientific simulations. Based upon a review of educational simulation software, Schmucker (1999) has proposed that educational simulations:

- create (or re-create) a phenomena, environment, or experience;
- provide an opportunity for understanding;
- are interactive (i.e. the user's inputs have some effect upon the course of the simulation);
- are consistent models of a theory;
- are unpredictable in their behaviour, either because of inbuilt randomness or else extreme sensitivity to user inputs.

Two main classes of educational simulation exist: those based on operational models (which are used in areas such as medical and pilot training), and those communicating conceptual models (which are used within conventional science education).

Operational simulations are designed to facilitate the construction of practical knowledge and do so by allowing students to both practically and psychologically play the role that they are being trained to perform (e.g. the role of a surgeon or pilot) (de

Jong & van Joolingen, 1998; Leemkuil, de Jong & Ootes, 2000). To this end, operational simulations often use non-standard input and output mechanisms. Medical students, for example, might make use of a special *haptic* (touch) output device in order to allow them to feel virtual tumours in virtual livers or to assist their general surgical training (Gibson et al., 1998; Langrana, Burdea, Ladeji & Dinsmore, 1997). Likewise, full scale (mechanical integrated with computer) simulations of human bodies are used in obstetrics and anaesthesia training (Sá Couto, van Meurs, Bernardes, Marques de Sá & Goodwin, 2002), while full-scale simulations of cockpits are used within pilot training.

In contrast with operational simulations, conceptual simulations are designed to facilitate the construction of conceptual knowledge and they do this by simulating the relationships that exist between the variables of a real-world system and by allowing the user to manipulate these variables. Conceptual simulations vary in complexity. At the most complex end of the spectrum are the domain-independent, simulation development-environments that allow users to create their own complex simulations. At the least complex end of the spectrum are the educational applets (also known as *interactive diagrams* – Confrey, Filho & Maloney, 2002) which are simple web- or CD-ROM-based simulations that permit users to vary certain of their parameters. Educational applets may be found on many university web sites and are frequently used as supplements to classroom lectures and traditional labs (Masters, 2002). An example of an educational applet is shown in Figure 19.

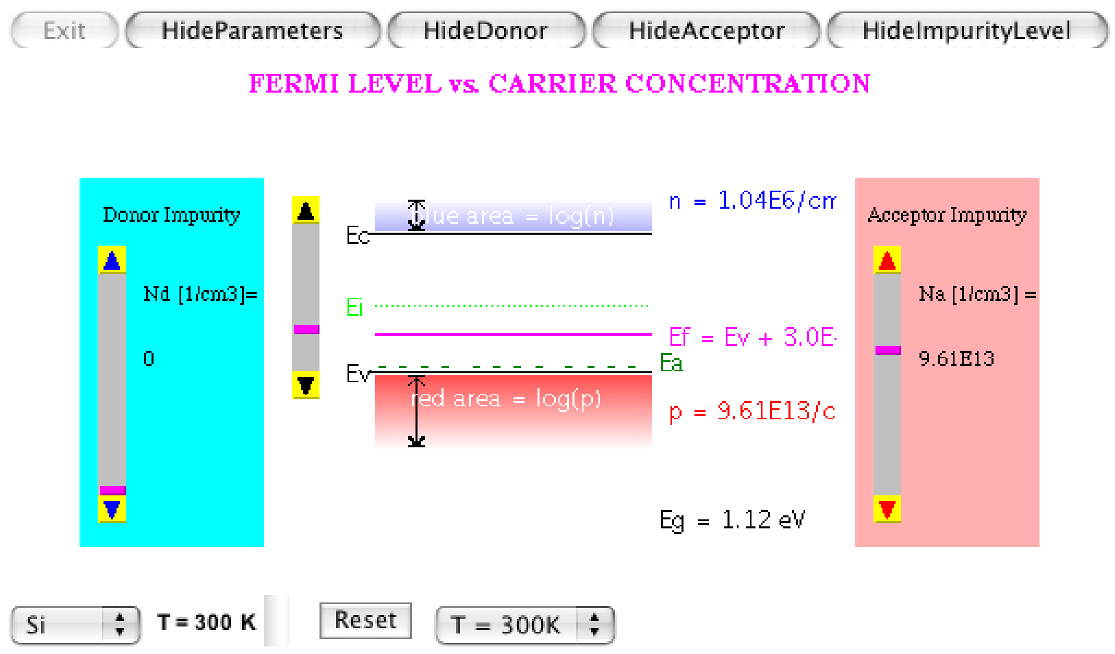


**FIGURE 19** – An educational applet♠.

Conceptual simulations are usually made up of two main components: a mathematical model of the target system (i.e. the simulation proper) and an instructional overlay, and these two components collectively define the body of knowledge to be learned and how the learning is intended to be accomplished (Colella, Klopfer & Resnick, 2001; Davies, 2002; Granlund, Berglund & Eriksson, 2000; Rieber et al., 1996). While the mathematical models upon which *operational* simulations are based need to be as realistic as possible (since they are being used for training in specific real-world procedures such as medical procedures – Gibson et al., 1998), the mathematical models upon which *conceptual* simulations are based are usually simplified to some degree in order to facilitate learning (Davies, 2002; Oxenham, 1982). Such simplification is

♠ Retrieved December 10, 2003, from http://jas.eng.buffalo.edu/education/semicon/fermi/bandAndLevel/fermi.html.

necessary because with increased realism comes increased complexity (Naylor et al., 1966), and as complexity increases so does the time required by students to understand the simulation, and so also does the likelihood that students will become frustrated and demotivated (Bos, 2001). By reducing simulation realism, therefore, the conceptual-simulation designer can clarify concepts for the student and can tailor the simulation to the student's knowledge and experience (Elton et al., 1978; Goosen, Jensen & Wells, 2001; Granlund et al., 2000; van Rosmalen & Hensgens, 1995).

The second component of a conceptual simulation – the *instructional overlay* – is made up of those features that guide, prompt and motivate users, and stop them from becoming lost (Leemkuil, de Jong & Ootes, 2000; van Rosmalen & Hensgens, 1995, cf. Lee, Nicoll & Brooks, 2004). An instructional overlay can incorporate questions that will help direct students towards educational goals, can focus students' attention upon educationally important aspects of the simulation (Hmelo & Day, 1999), and can progressively unfold a simulation's complexity over a series of stages in order that students not be overwhelmed by it (a process known as *model progression*). To consider some examples of model progression, educational simulations can initially present students with: qualitative models and then progress to quantitative models; a few variables and gradually increase their number; a model based upon simple rules and then add more complex rules (de Jong et al., 1999; Leemkuil, de Jong & Ootes, 2000; Swaak, van Joolingen & de Jong, 1998).

# Why Use Educational Simulations?

Educators have found simulations to be (a) in some ways superior to traditional textbooks and lectures, (b) able to provide experiences that are difficult or impossible for students to gain any other way, and (c) able to facilitate various desirable types of learning and knowledge construction.

## 1. Superior to Traditional Textbooks and Lectures

Simulations can prove educationally superior to lectures and textbooks in that they (a) can provide richer experiences for students, (b) can provide more direct access to the subject domain, (c) can visualise abstract/dynamic concepts, and (d) are interactive.

### (a) Rich Experiences

*Richness* relates to the amount of information that can be extracted from a pedagogical source by a learner and also to the multiplicity of ways that this information can be obtained (Swaak et al., 1998). Simulations provide rich environments within which to learn and richer experiences than can be gained through textbooks alone (Thomas & Neilson, 1995). For example, students using a computer-based clinical diagnostic simulation are able to pursue their own personalised line of enquiry with a particular simulated patient, and because of this, subsequent discussions regarding the simulation experience allow students to coordinate their multiple points of view regarding what the correct diagnosis should be (Hmelo & Day, 1999).

### (b) More Direct Access to Subject Domain

Simulations provide more-direct access to a subject domain than do verbal descriptions, and this access in turn allows students to directly investigate the inter-relationships of the variables that define the domain and to gain experiences that can help them to solidify their understandings and to form concepts (Marasinghe, Meeker, Cook & Shin, 1996; Roccetti, Salomoni & Bonfigli, 2001; Thomas & Neilson, 1995). In order to give the abstractions and mathematical equations taught in science classes meaning, students must be provided with experiences that correlate with them. Often, however, these experiences cannot be provided in real life because the equations refer to phenomena (such as complex systems) that are invisible, abstract, or intangible and that cannot therefore be directly experienced, played with, or controlled (Jenkins, 2002a). Moreover, students' real-life experiences of phenomena are often confounded with invisible factors that distort or contradict the principles they need to master in science classes. So for example, in real life people are unable to experience frictionless planes or ideal gases (Dede, Salzman, Loftin & Ash, 2000; Dede, Salzman, Loftin & Sprague, 1999). Simulations, however, can offer their users direct experiences of these intangible, abstract, ideal, complex, or otherwise unavailable phenomena and thus can facilitate knowledge construction regarding them (Edwards, 1998; Greenfield, 1984; Papert, 1980). In addition, the inappropriateness of a student's alternative scientific conceptions is revealed more effectively through the direct experiences provided by simulations than when students are simply told by an educator that they are wrong (Tao, 1997; Thomas & Neilson, 1995).

### (c) Visualisation

Lectures and labs employing chalk drawings, mathematical equations, textbooks and laboratory specimens (such as cadavers) are static and thus cannot capture and transmit the dynamic and causal nature of real-world phenomena. In contrast, simulations are dynamic and thus can allow the visualisation of dynamic and causal processes (Budhu, 2001; Clark & Jorde, 2004; Hokanson & Hooper, 2000; Kamthan, 1999; Wu-Pong & Cheng, 1999; Zhu, Zhou & Yin, 2001). Visualisation is useful for illustrating the movements of a system that are normally not visible (such as the flow of electrons in a wire or blood in a living human) and for helping students to understand highly theoretical and complex mathematical ideas that are hard to conceptualise when learned about through teaching or reading (Härtel, 2000; Huddle & White, 2000; Nehring, Ellis & Lashley, 2001; Ricci & van Doren, 1997; Weiss, Knowlton & Morrison, 2002; Zhu et al., 2001). Simulations can support a variety of data display formats (such as pictures, animations, graphs, vectors, and numerical data) and can thus can allow learners to relate to a system in a number of ways. Moreover, because each format transmits some kinds of information better than others, the ability to choose particular display formats for particular information allows educators to represent material in the best possible way for a given user group (Jimoyiannis & Komis, 2001; Mintz, 1993).

### (d) Interactivity

When using simulations, students directly manipulate objects and observe the effects of doing so, and as a result they are better able to internally visualise the simulated system and to reason abstractly about it (Pilkington & Parker-Jones, 1996). Additionally, when using simulations students can engage in pedagogically useful activities such as making predictions, testing ideas and assumptions, experimenting with scenarios, and discovering how manipulation of one variable affects other variables (Jimoyiannis & Komis, 2001; Shneiderman, 2000; van Rosmalen & Hensgens, 1995; Weiss et al., 2002). Moreover, because simulations allow the user to immediately see the consequences of their actions and to perceive an immediate connection between hypotheses and results, their use is both beneficial for learning and more compelling than textbook-based learning (de Jong, de Hoog & de Vries, 1993; Gorman, Meier & Krummel, 1999; Mintz, 1993).

## 2. Experiences Difficult or Impossible to Gain Any Other Way

Simulations may be thought of as virtual laboratories in that they allow students to gain practical experiences of scientifically relevant variables in much the same way that they would in a physical lab (Baillie & Percoco, 2000; Huppert, Yaakobi & Lazarowitz, 1998; Mintz, 1993; Talia & Sloot, 1999). Additionally, however, simulations can be used to teach material that cannot be taught by conventional laboratory experimentation because such experimentation is too:

(a) difficult or impossible for reasons of skill;

(b) dangerous;

(c) difficult or impossible for reasons of physical or temporal scale;

(d) ethically problematic;

(e) complex;

(f) expensive (or the materials required are too rare).

### (a) Difficult or Impossible for Reasons of Skill or Technical Complexity

Simulations are simpler and more rapidly implemented than physical labs and can thus allow even the least skilled students to quickly explore complex experimental situations (Jimoyiannis & Komis, 2001; Mintz, 1993; Thomas & Neilson, 1995). Moreover, because it is difficult to write up and interpret data confounded by the spurious, incomplete, or inconsistent results obtained from *in vivo* lab work, simulation use can enable students to utilise lab time more productively and to concentrate on experiment design rather than upon basic data collection (Hughes, 2001; Mackenzie, Earl, Allen & Gilmour, 2001). While it might seem that students who use simulations instead of attending practical labs might be at a disadvantage because of a lack of practical experience, in fact a great many things learned in practical labs are only of interest to people who will go on to work in labs, and generally most students will not do so (cf. Hughes, 2001). Apart from those situations in which simulation use makes practical work easier, there are important areas where such work would be impossible without simulations. The most obvious examples of these are medical and pilot training where a student might need to be quite expert in using certain equipment before being allowed to undertake even basic tasks. The same is also true for the use of complicated and expensive scientific equipment (Mcateer et al., 1996).

### (b) Dangerous

Sometimes laboratory work or practical training in an area is not possible because it would be too dangerous. Lab work or training might involve explosive mixtures, radioactive materials, toxic chemicals, virulent pathogens, high pressures and temperatures, or dangerous emergencies (Cartwright & Valentine, 2002; Ellington, Addinall & Percival, 1981; van Rosmalen & Hensgens, 1995). Because simulation use allows hazardous processes and dangerous variables to be safely incorporated into a university laboratory, learners can explore the elements of the simulated system, change variables, and discover consequences without suffering distress or danger when they make mistakes (Corbeil, 1999; Huppert et al., 1998; Kuriyan, Muench & Reklaitis, 2001).

### (c) Difficult or Impossible for Reasons of Physical or Temporal Scale, or Existing Physical Laws

Because simulations can compress or expand time and space they can be used to speed up otherwise slow or long term processes. Using simulations, therefore, students can conduct experiments concerning slowly changing systems (in areas such as astrophysics, nuclear physics, genetics, geology and ecology) and can better understand fast-moving processes (such as those occurring at the sub-atomic level) (Barab, Hay, Barnett & Keating, 2000; Ellington et al., 1981; Huppert et al., 1998; Mintz, 1993; Romme, 2002; van Rosmalen & Hensgens, 1995). Additionally, using simulations (or more precisely, *simulacra*) of non-real systems, students can investigate worlds that do not operate according to existing physical, chemical, biological, or psychological laws. Simulations can therefore assist in the investigation of *thought experiments* (e.g. regarding inverse gravitation), and can enable students to do things that are physically impossible (such as looking inside an atom) (Elton et al., 1978; Fishwick, 1995).

### (d) Ethically Problematic

Ethical restrictions on student education and training are important in a medical or biological sciences context where the objects under study are human beings or other living things. In such contexts simulations can allow students to practice making real world decisions about important situations without placing anyone or anything else at risk (Pilkington & Parker-Jones, 1996). Medical and nursing students can, for example, use simulations to explore the consequences of making poor decisions without compromising the safety and quality of care of patients (Christensen, Heffernan & Barach, 2001; Lane, Slavin & Ziv, 2001; Nehring et al., 2001). Simulations can also replace real human beings as patients when students require training in critical medical situations that have high risk to the patient, in new or complex medical procedures, and also in sensitive areas such as counselling for sexual abuse (Dorsey et al., 1996; Gorman et al., 1999; Sá Couto et al., 2002; Ziv, Small & Wolpe, 2000). Also, by using simulations in a biological-sciences-education context the use of live creatures is avoided and thus the ethical principles of students and staff need not be threatened (Akpan & Andre, 1999; Mcateer et al., 1996).

### (e) Complex

When an educator wishes to teach or train students regarding some real world situation, but that situation is too complex to be dealt with directly, simulation use can provide a solution (Christensen et al., 2001; Peters, Vissers & Heijne, 1998; van Rosmalen & Hensgens, 1995; Ziv et al., 2000). Simulations are valuable when factors involved in a given phenomenon are too numerous to be controlled under conventional laboratory conditions (Huppert et al., 1998; Mintz, 1993), they can reduce the complexity faced by students by dealing with (or else abstracting away) unimportant details (Pullen, 2000), they can allow students to explore systems without extensive knowledge of mathematics or prolonged mathematical manipulations (Thomas & Neilson, 1995; Toby & Toby, 1999), and they can assist students to construct improved understandings of emergent phenomena (Resnick, 1991).

### (f) Expensive, or Materials are Rare

Simulations can be inexpensive compared with labs (such as those in high-energy-, nuclear-, or reactor-physics and concerning industrial processes of all types) that require the purchase and maintenance of, and/or multiple sets of, expensive experimental equipment and materials (Bass, 1997; Budhu, 2001; Cartwright & Valentine, 2002; Ellington et al., 1981; Mackenzie et al., 2001; Mcateer et al., 1996; van Rosmalen & Hensgens, 1995). Additionally, simulations can substitute for a shortage of equipment, which is particularly important in medical situations where cadavers, patients, and particular medical conditions can all be rare (Gibson, et al., 1998; Gordon, Issenberg, Mayer & Felner, 1999; Gorman et al., 1999; Sá Couto et al., 2002; Ziv et al., 2000; Zhu et al., 2001). Moreover, using simulations students can repeat, redo, or rehearse difficult experiments and training procedures as many times as necessary for the problem to be solved or understood, but without using up any extra resources (Budhu, 2001; Gibson et al., 1998; Jimoyiannis & Komis, 2001; Mintz, 1993).

## A Caveat

While simulations can be both less expensive and less time-consuming than practical labs, they can nonetheless still be both expensive and time-consuming to use. Educational simulations are expensive to produce, and because the educational software market is small they are expensive to buy. While it might be possible for educators to instead make use of industrial or academic simulation software, such software may be too complex to use or else may not transfer well to an educational environment because of unacceptable content or style, poor usability, and/or poor programming standards (Thomas & Neilson, 1995; cf. Martínez-Jimenéz et al., 1997). A significant investment in time is also needed on the part of both the student and educator when using simulations as educational tools (Romme, 2002, Davies, 2002; Oxenham, 1982). Because the benefits of using simulations can be lost if students are not proficient with them and become frustrated, it is thus important that students receive adequate instruction both in computer skills and in using the simulation software itself (Bass, 1997). The provision of this instruction will, however, reduce the amount of time available for dealing with the content of the course and will also interrupt the flow of conceptual learning regarding this content, and thus studying by computer simulation may end up being more time-consuming and complicated than learning from a textbook (Kim, Kim, Min, Yang & Nam, 2002; Oxenham, 1982).

## 3. Desirable Types of Learning and Knowledge Construction

Using simulations students can engage in (a) active and problem-based learning, (b) situated and experiential learning, (c) construction and collaboration, (d) exploratory and discovery learning, (e) change of alternative conceptions, and (f) qualitative knowledge construction, all of which are educationally desirable.

### (a) Active and Problem-Based Learning

"[Simulations] interest and motivate learners. They offer more than just intellectual involvement. They engage the emotions and provoke reactions . . . " (Oxenham, 1982, p. 2). Simulations allow students to engage in authentic and meaningful activity – such as solving real-world problems – and this authentic activity facilitates students' active engagement in the educational tasks they are to perform (Baillie & Percoco, 2000; Christensen et al., 2001; Davies, 2002; Huppert et al., 1998; de Jong et al., 1993; Jimoyiannis & Komis, 2001). Moreover, such authentic activity is centred on the work of the participant (rather than on that of the educator), is thus intrinsically interesting and motivating, and can therefore allow educators to avoid having to use external sources of motivation (Corbeil, 1999; Davies, 2002; Wong, Packard, Girod & Pugh, 2000).

### (b) Situated and Experiential Learning

The linkage of learning to action is a central concern in education (and particularly in adult education and training), and simulation use can enable this linkage to occur (Oxenham, 1982). Because simulations enable a safe environment for making real world decisions they allow students to practice making decisions that closely resemble those that practitioners in their field must make (Pilkington & Parker-Jones, 1996). Moreover, because simulations place information in a lifelike contextual framework they not only allow users to gain a greater understanding than they could using traditional pedagogical methods, but this understanding will also transfer more easily from the educational context to real-life (Gorman et al., 1999). Additionally, the experience-based instruction provided by simulations accommodates more complex and diverse approaches to learning than do traditional methods and facilitates both cognitive and affective learning (Bos, 2001; Ruben, 1999).

### (c) Construction and Collaborative Learning

It is a central tenet of *constructionism*, a subsidiary philosophy to constructivism, that knowledge construction is facilitated through physical construction: that is, through the construction of *public entities* (e.g. sand castles, games, software) (Papert & Harel, 1991). Just as the process of constructing and testing models helps scientists develop better models of natural systems (Naylor et al., 1966), so too can this process assist students to improve their own understandings (Repenning, Ioannidou & Phillips, 1999; Spector, 2000). Most especially with regard to complex systems, the process of model building helps students improve their understanding of how a system works and why it works that way, and also facilitates the transfer of learning to real world settings (Colella et al., 2001; Penner, 2000; Spector, Christensen, Sioutine & McCormack, 2001).

The processes of constructing a model, of constructing software, and of constructing media (all of which are engaged in when constructing simulations) facilitate knowledge construction by: engaging students in questioning, predicting, and verifying their ideas (Jackson, 1995); requiring students to articulate and thus reflect upon their ideas and knowledge (Guzdial, 2001); and by encouraging students to develop new ways of thinking about computation, programming, and behaviour (Resnick, 1993). Moreover, these processes encourage a sense of ownership of the resultant product even amongst students who have little or no intrinsic interest in the specific content they are dealing with (Harel & Papert, 1991; Jackson, 1997).

Scientific software construction assists students to learn how to express themselves in a technological domain, provides authentic and personally relevant problems for students to solve, fosters the integration of isolated and fragmented knowledge, fosters the integration of scientific knowledge and programming knowledge, and requires the construction and understanding of scientific content (Hay et al., 2000; Kafai, Ching, Marshall, 1997; Stratford, Krajcik, & Soloway, 1998). Additionally, the process of constructing simulations encourages collaboration between students since by working together students can: assist one another in their designs; review and critique each other's work; serve as forum and an audience for one another; and can provide feedback and conversation for one another. These processes in turn help to refine their concepts and challenge their understandings (Barab et al., 2000; Guzdial, 2001; Hay et al., 2000; Kafai et al., 1997; Kafai & Harel, 1991; Stratford et al., 1998). Even in the absence of a construction task, however, students still like to work collaboratively with simulations (Beichner et al., 1999; Tao & Gunstone, 1999).

## (d) Exploratory and Discovery Learning

When using simulations students become involved in a process of exploratory or scientific discovery learning (de Jong & van Joolingen, 1998; Granlund et al., 2000). This type of learning involves hypothesis generation (starting with an hypothesis and trying to find evidence for or against it), data interpretation (collecting data and then looking for regularities), and also engages the learner in inferring the characteristics of the model underlying the simulation from its input/output relationships (de Jong et al., 1993; de Jong & van Joolingen, 1998; Swaak et al., 1998; van Rosmalen & Hensgens, 1995). Fundamentally, simulations allow students to ask "what would happen if . . . " and then to go and find out for themselves – free from the technical constraints that hamper laboratory- and real-world-based exploration (Elton et al., 1978).

## (e) Change of Alternative Conceptions

As a result of their everyday experiences, students develop intuitive ideas of how natural systems operate long before they receive any scientific education relating to these systems. A variety of such *alternative conceptions* (i.e. alternative to *scientific* conceptions) have been documented: students often have trouble, for example, distinguishing heat from temperature, acceleration from velocity, and in realising that stillness and motion are fundamentally alike (Clark & Jorde, 2004; Monaghan & Clement, 2000). Alternative conceptions have the general characteristics of being poorly articulated, internally inconsistent, and highly dependent upon context, yet because they often have significant explanatory power in the mind of the student they can be very difficult to change (Windschitl & Andre, 1998). As a consequence of these conceptions being quite different from those developed by scientists (Härtel, 2000), scientific knowledge construction frequently involves not only the *absorption* of new concepts but also a *change* of concepts (Tao, 1997). A common instructional strategy to foster conceptual change is to confront students with discrepant events that contradict their existing conceptions, and computer simulations and simulation-based games can be used to provide these discrepant events (Dede, Salzman & Loftin, 1996a; Edwards, 1998; Lee et al., 2004; Monaghan & Clement, 2000; Windschitl & Andre, 1998). Additionally, using simulations students can freely manipulate and explore the simulated world and can spontaneously formulate and test their hypotheses regarding how that world will behave, and this also facilitates conceptual change (Tao & Gunstone, 1999).

## (f) Qualitative Knowledge Construction

In contrast with quantitative knowledge (which is based upon formal representational constructs such as formulae, rules, algorithms, and precise values), qualitative knowledge of a system takes the form of qualitative values and relationships (e.g high, forward, underneath). Now, because qualitative understandings of phenomena are developed prior to quantitative understandings[♣], and also because a person's alternative conceptions of a system take a qualitative, as opposed to a quantitative form (Foley, 1997; Mioduser, Venezky & Gong, 1996), it is educationally desirable that students are able to develop their qualitative understandings of a system before they must deal with it

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♣ For example, before accurate quantitative predictions could be made regarding the locations of the planets amongst the stars as viewed from Earth, a qualitative theory of the structure of the 'heavens' first had to exist. The transition between the Ptolemaic and Copernican astronomic systems was in the first instance a qualitative one and it was this qualitative change (rather than the quantiative improvements that followed) that caused the greatest concern within the non-astronomical community (cf Kuhn, 1957).

mathematically. Traditional science teaching typically involves the student dealing with quantitative mathematical methods before they can understand the subject matter. Science teaching using simulations does not suffer from this problem, however, because simulations provide direct experiences of phenomena without requiring the use of mathematics (Cartwright & Valentine, 2002; Christian & Titus, 1998; de Jong et al., 1993; de Jong & van Joolingen, 1998; Fontan et al., 1998; Härtel, 2000; Huppert et al., 1998; Kofke & Mihalick, 2002; Rieber et al., 1996, Walford, 1982).

## Evidence for the Educational Effectiveness of Simulations

While conventional educational methods are usually considered valid until proven otherwise, the effectiveness of innovative educational methods must be amply demonstrated before they receive support or approval (St-Germain & Laveault, 1997). Simulations are innovative educational tools and many educational researchers have investigated their effectiveness♣, yet currently the only thing that can be said with assurance about the educational effectiveness of simulations is that nothing can be said with any assurance. The effectiveness of simulations compared to traditional methods is debatable (Kim et al., 2002), and evidence in favour of their use is limited, preliminary, controversial (Christensen et al., 2001; Herz & Merz, 1998), mixed (Goosen et al., 2001), inconclusive (Dekkers & Donati, 1981) and equivocal (de Jong & van Joolingen, 1998; Gorman et al., 1999; Wu-Pong & Cheng, 1999). Basically, there is no consensus on the subject (Swaak et al., 1998) and it is not really known how they compare with traditional techniques in terms of effectiveness (Leemkuil, de Jong & Ootes, 2000;

♣ And over a long period. See Dekkers & Donati (1981).

Wolfe & Crookall, 1998). Some stress the negative side of this uncertainty and suggest that there is little published evidence to show that simulations are effective in achieving appropriate learning objectives and that the promised benefits of educational technologies of all kinds including computers (especially computers) have failed to accrue (Hokanson & Hooper, 2000; Hughes, 2001). Others note, however, that educationally oriented computer-based simulations are growing in number in spite of continuing debates in the academic literature regarding their educational effectiveness (Spector et al., 2001).

Whatever perspective one takes on the subject, the reasons for the lack of certainty are straightforward: namely, that educational outcomes are in general difficult to quantify, evaluate and assess (Baillie & Percoco, 2000; Huddle & White, 2000; Swaak et al., 1998), and that there is no objective and neutral method of assessing educational effectiveness (Elton et al., 1978; Rubin, 1996). There are a number of reasons why educational effectiveness is difficult to assess. First, it is not possible to control the numerous factors that inevitably confound an educational experiment, such as the experimenter's enthusiasm, ceiling effects, poor students dropping out, the impossibility of independence among the items of study (i.e. students), and the inability to properly randomise(Wang, 1993). Second, it is easy to bias the design of experiments dealing with educational effectiveness (i.e. through choice of controls), and third, it is difficult to unequivocally demonstrate that a participant's learning success results from using a particular method rather than from some other source (Ju & Wagner, 1997). Since experimentation cannot ever conclusively demonstrate the benefits of *any* given educational methodology (Wolfe & Crookall, 1998), therefore, the absence of consensus regarding the educational effectiveness of simulations should come as no surprise. Educators who believe in the value of simulations have not waited around for them to be proven effective, however, and thus the lack of conclusive evidence in their favour has not constituted an insurmountable obstacle to their use.

## Summary

This chapter has revealed a number of attributes of educational simulations that facilitate scientific knowledge construction. Just like scientific simulations, educational simulations are able to re-create reality and thus they allow students to investigate systems that normally lie beyond their reach: many educationally interesting systems being too expensive, dangerous, complex, or physically inconvenient for students to investigate directly. Not only can educational simulations re-create realities, they can also allow students to interact with and visually perceive them, and this quasi-direct access provides students with richer experiences than they could obtain using textbooks or from lectures. These rich experiences, in turn, enable students to construct qualitative knowledge, and this qualitative knowledge can help them to challenge their erroneous alternative conceptions.

Unlike the contrived and irrelevant problems presented in textbooks and labs, the problems that simulations present their users are genuine (within the simulation context), the process of solving them engages students in the practice of science (i.e. active exploration, discovery, theorising and experimentation), and the knowledge thus constructed transfers more easily to real-life contexts than does knowledge constructed through reading alone.  Simulation construction too assists knowledge construction, both directly, and indirectly when students collaborate in the context of a construction task.

*Those who conceive of videogames as a mindless indulgence that encourages antisocial impulses will regard as preposterous and potentially dangerous the notion of a college course that resembles a videogame.*

*(Foreman, 2003, p. 12)*

CHAPTER SIX

# Educational Games

Educational games share attributes of both simulations and games and thus the purpose of this chapter is to determine both in what ways educational games can facilitate the construction of scientific knowledge, and what attributes of games make them enjoyable to play. This chapter describes what educational games are, why they are used, and what issues affect their design.

## What is an Educational Game?

Within much of the literature dealing with educational simulations little distinction is made between them and educational games (Leemkuil, de Jong & Ootes, 2000; Rubin, 1996)[♣], and similarly, educational games are usually listed as a genre of interactive entertainment (cf. Chapter Three). Nonetheless, educational games may usefully be distinguished from both of these other two types of artefact.

The process of distinguishing educational games from educational simulations is somewhat complex because, as we have seen (and will see), there are two types of educational game and two types of educational simulation. The relationship between the two types of educational simulation (operational and conceptual) and two types of educational game (process-intensive and data-intensive) is described in Table 4.

**TABLE 4** – The main differences between educational simulations and games (a modified version of a table found in Leemkuil, de Jong & Ootes, 2000).

| | Underlying model | Goal | Competition | Constraints | Alternate Reality |
|---|---|---|---|---|---|
| Operational Simulations | Yes | Yes | No | Yes | Yes |
| Conceptual Simulations | Yes | No | No | No | No |
| Data-intensive Games | No | Yes | Yes | Yes | Yes |
| Process-intensive Games | Yes | Yes | Yes | Yes | Yes |

The most common form of educational simulation is the conceptual simulation, while the most common form of educational game is the data-intensive game, and so far as Table 4 is concerned these two types of software have nothing in common at all. Data-intensive games, that is, are *not* based upon mathematical models but they *do*: provide their users with a goal to accomplish; involve their users in competition; constrain the actions of their users (i.e. the kinds of 'moves' they can make); and they do involve their users in an alternative psychological reality. Conceptual simulations, by contrast, *are*

[♣] The literature reviewed in this chapter concerns both games and *microworlds*: software tools that are like simulations but which are simpler in structure and easier to use and understand, and which are thus more suited to use by children (Leemkuil, de Jong & Ootes, 2000; Rieber, 1996).

based upon mathematical models and possess none of these other features. Process-intensive educational games are also based upon mathematical models, but otherwise possess similar features to data-intensive educational games.

One might expect that the principal difference between conventional games and educational games would be that players learn something when playing the latter but not when playing the former. This expectation would be a false one, however, because apart from in the most trivial cases (e.g. tic-tac-toe) gameplayers *always* learn something when playing a game (i.e. how to get better at playing the game). This objection granted, it might then seem that the principle difference between conventional games and educational games must be that players learn something *of practical use* when playing the latter but not when playing the former. This expectation too is false, however, not only because playing many games (digital or otherwise) develops physical and/or cognitive skills that may be applied outside gameplaying (Aguilera & Mendiz, 2003; Gros, 2003; Mayer et al., 1999), but also because, for serious game players, learning how to improve one's game performance *is* of practical use, just as learning how to improve one's flying is of practical use to a pilot. The two actual differences between conventional games and educational games are that (1) what is learned while playing an educational game is considered by educators and/or parents to be of educational value, whereas what is learned when playing conventional games is usually considered by these groups to be of no value at all, and (2) educational software is chosen by teachers and parents but not used by them, whereas conventional games are chosen (or at least approved of) by the players themselves (Gros, 2003). An implication of these two differences is that what makes a game an *educational* game is not the nature of that game itself but is rather the way that the game is perceived collectively by teachers, parents, and players. So for example, a flying instructor and her students would consider a flight-simulation game to be educational, whereas a biology lecturer and her students would consider it to be simply a game. The web-site for the neural-function simulation *NeuroSim* boasts that "For a budding electrophysiologist this could become as addictive and much more useful than almost all computer games" and that "For sheer intellectual enjoyment this program is hard to beat"♣, and thus even quite serious educational simulations may be related to as games if users are interested enough.

Despite the fact that digital games are routinely designed with either education or entertainment in mind (Myers, 1999), the line between these two functions is somewhat blurred and this is because: some makers of interactive entertainment incorporate educational content into their games; some makers of educational software attempt to make their products entertaining; some educators appropriate interactive entertainments for educational purposes; and because many parents eschew popular games in favour of educational games for their children (Brody, 1993; Game-Research.com, 2002; Greenfield, 1984; Rollings & Morris, 2000; Squire, 2001b). It makes most sense, therefore, to think of the educational and entertainment roles that games can fulfil as defining the ends of a continuum (as does Schmucker, 1999, for example).

♣ Retrieved April 16, 2004 from http://www.biosoft.com/w/neurosim.htm.

## Two Classes of Educational Game

Educationalists tend to fall into one of two philosophical camps, which Dewey labelled as *traditional* and *progressive* (Dewey, 1938), and which are now often referred to as *instructivist* and *constructivist* (Leemkuil, de Jong & Ootes, 2000; Margules, 1996). While there are a number of differences between these philosophies, the most important from the point-of-view of game design is the way in which they each envisage the learning process. As was discussed in Chapter Two, from a constructivist perspective learning takes place when people interact with their environment while they engage in problem solving, and thus an important part of an educator's job is designing interactions. By contrast, from an instructivist perspective the mind of a learner is, metaphorically speaking, an empty page upon which the educator writes, and thus an important part of an educator's job is deciding what to write there. Now it happens that these two educational philosophies bear an affinity with the two styles of game design discussed in Chapter Three (i.e. process-intensive and data-intensive game design), in that, just like constructivist teachers, process-intensive game designers are primarily concerned with what sort of interactions the game player will engage in, while data-intensive game designers (just like instructivist teachers) focus upon selecting the appropriate data with which to stock their games. Moreover, just as instructivism is far more popular (in practice, if not theory) than constructivism within most school classrooms, so too are data-intensive educational games more prevalent within the world of educational games than are process-intensive educational games. Below, both data-intensive and process-intensive educational games are discussed.

## Data-Intensive Educational Games

Data-intensive educational games (most usually referred to as *edutainment*) have tended to be rejected by both educators and game critics as being neither educational nor entertaining (Brody, 1993; Egenfeldt-Nielsen, 2002; Hall, 2001; Jenkins, 2002a; Kirriemuir, 2002b; cf. Falbel, 1991):

> Much of what goes under the name "edutainment" reminds me of George Bernard Shaw's response to a famous beauty who speculated on the marvellous child they could have together: "With your brains and my looks . . ." He retorted, "But what if the child had my looks and your brains?" Shavian reversals – offspring that keep the bad features of each parent and lose the good ones – are visible in most software products that claim to come from a mating of education and entertainment. (Papert, 1998, p. 1)

There are three main factors that make edutainments both uneducational and unenjoyable, and these are that they tend to possess low quality graphics and sound (BECTA, 2001; Dede, 1995; Games-to-Teach, 2000b; Gros, 2003; Jenkins, 2002a), that their challenges are artificial, and that their interactivity is deficient. The latter two factors are discussed below.

The challenge provided by edutainment tends to take a similar form to school work and consists of exercises, drills, memorisation, puzzle-solving, and guessing (assisted by the provision of clues and facts) the correct answers to directly asked questions (Brody, 1993; Buckingham & Scanlon, 2000; Jenkins, 2002a; McFarlane et al., 2002; Price & Rogers, 2003). Unlike educational simulations, which incorporate the material to be learnt within the structure of the simulated world, within edutainment the educational content is quite separate to the gameworld and is artificially overlayed on top of it (Games-to-Teach, 2000b). So for example, in a very old (but nonetheless quite representative) educational game called *Darts* (cf. Malone, 1981), the 'player' must attempt to hit a target (located somewhere on a number scale between two whole numbers) using a set of darts. The player does not aim visually, however, but rather *mathematically* by guessing what fraction sits closest to the target's location. In the conventional game of darts the challenge is one of hand-eye coordination and the player plays darts because they intrinsically enjoy this type of challenge. By contrast, the challenge that faces the player of the *Darts* game is a mathematical one and the player is not expected to intrinsically enjoy it (since if they did there would be no need of the pretence that they were playing darts). All edutainment makes use of pretence like this and because users are not expected to intrinsically enjoy the challenge presented to them edutainments frequently employ a rewards system to motivate players – messages such as "well done" (Brody, 1993; Games-to-Teach, 2000b). These rewards are so important to edutainment that often more time is spent creating them than in designing the educational content itself (Rubin, 1996). So for example, in the edutainment *Childsplay* (depicted in Figure 20), most of the design effort (what little there is of it) has gone into beautifying what is essentially a simple mathematical quiz.

As was discussed in Chapter Three, a great deficiency of games based upon anticipatory systems is that they lack interactivity, and this is also the case with edutainment (Price & Rogers, 2003). Just as the designer of interactive fiction wishes to tell an interesting story (and so creates only those pathways through the gameworld that *will* tell an interesting story), so too the designer of edutainment wishes to convey some specific educational information or content to the player and does so by limiting the player's choices to only those that will convey this information or content (Smith, 2002b).

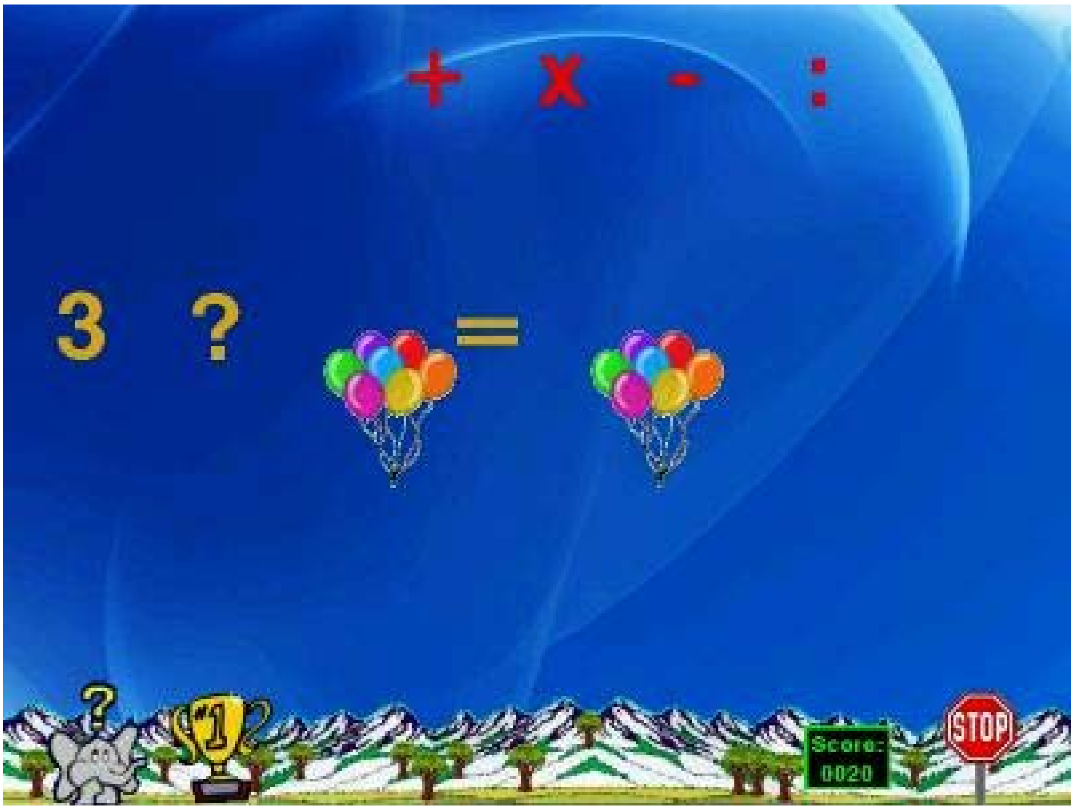


**FIGURE 20** – Screenshot of a typical edutainment, *Childsplay, version 0.65*♠.

Gameplayers are not, however, usually interested in a game's content. "Playing a game, one gradually ignores the story and graphics to focus exclusively upon the *structure* of the game, i.e. what manoeuvres it takes to complete the game – no matter what the game 'is about'" (Juul, 1999, p. 7), and thus attempting to use a game's content rather than structure to convey educational information is counterproductive. Moreover, the ability to control gameworld events is a central motivating feature of gameplaying and thus by

♠ Retrieved January 05, 2004, from http://childsplay.sourceforge.net/images_shots/chpl_num.jpg.

abandoning interactivity the designers of edutainment also abandon player enjoyment (BECTA, 2001; Crawford, 1996c; Fauth, 1995; Juul, 1999).

Before leaving the topic of edutainment it is should be noted that some of the ideas presented above have been contested. Rieber, Davis, Matzko and Grant (2001) note, for example, that "*Math Blasters*, one of the all-time best selling educational titles, largely fails in the integration of game and content" (p. 2), and this does argue against the idea that content *must* be integrated with the gameworld. Similarly, educational researchers have felt that the adventure game genre possessed merit because its storylike qualities provide it with the potential to communicate educational content within a narrative structure (Amory, Naicker, Vincent & Adams, 1999; Gros, 2003; Ju & Wagner, 1997; McFarlane et al., 2002). Moreover, games such as *Where in the world is Carmen San Diego* have proved lastingly popular with children, educators, parents, and even game critics (cf. Anderson, 2002), and these games are data-intensive, not process-intensive.

It is not being proposed in this thesis that data-intensive entertainments are incapable of being enjoyable or educational, however, but only that they are inferior to process-intensive games in these respects. Moreover, since very few process-intensive educational games exist it is not so surprising that the most popular educational games have been data-intensive. Data-intensive games (whether educational or entertaining) possess an innate advantage over simulation-based games in that they can incorporate high-quality *events* (i.e. sounds, images, stories) which simulation technology is incapable of producing algorithmically. So for example, in an adventure game, non-player characters can talk to the player in English about dramatically interesting events, but only because their speech has been pre-scripted. Similarly, in the game *Myst* the visual scenes are truly beautiful, but only because they have been created as paintings. The innate disadvantage of data-intensive compared with process-intensive games is that they rely upon illusion and pretence. Such games attempt to fool the player into believing that they are interacting with a simulated world and have freedom of choice whereas in reality the player can only do what the game-designer has anticipated for them. To the degree that the player is willing to suspend their disbelief then data-intensive games can be more enjoyable than process-intensive games, yet the gameplay afforded by such games can never extend beyond puzzle-solving, and the educational benefits of such games can never extend beyond those offered by the classroom.

## Process-Intensive Educational Games

All process-intensive games possess the characteristics of constructivist learning environments in that they engage the user in:

- self-motivated learning.
- experimentation, reflection, and (at least potentially) collaborative discussion.
- solving personally meaningful, relevant, and genuine problems.
- interaction with concrete objects and situations (cf. Vosniadou, Ioannides, Dimitracopoulou & Papadematriou, 2001).

Thus, unlike the user of edutainment who is essentially "led by the nose" through a sequence of classroom exercises, players of process-intensive educational games can take charge of their own learning (Papert, 1998). The players of process-intensive games do not, however, think of what they are engaged in as learning (since their goal is not to learn but is rather to win) (Brody, 1993; Prensky, 2001; Wright, 2000), and thus they do not tend to approach game-playing in the way that a student approaches study. They don't, for example, tend to take notes during a game, nor do they tend to sit down after a series of games and analyse them consciously. Rather, much reflection about game performances is carried out sub-consciously and unintentionally (Crawford, 1996b) and game players consequently learn "surreptitiously and stealthily", not directly (Prensky, 2001). Edwards describes this process succinctly:

> Microworlds♣ are selfcontained worlds in which scientific regularities implicitly exist, available to be discovered by those exploring the microworld. The users induce these regularities by interacting with the environment. The regularities are not stated verbally or symbolically in any way, but are rather present in that objects within the microworld behave in accordance with these regularities. It is the non-explicitness of the regularities that make microworlds differ from other learning environments. The learner discovers the regularities in the course of solving problems or playing a game. The user must induce these regularities if they are to play the game successfully. An iterative or feedback process occurs in which the user compares their expectations about the behaviour of objects within the microworld with what actually happens. In other words, microworlds provide interpretable feedback (usually in real time) to the user. (Edwards, 1998)

Chris Crawford, writing from within an entertainment rather than educational tradition, says something very similar:

> The player tries out the game numerous times, each time experiencing a different instantiation. In this way, the player builds up a mental image of the truth of the game. It's as if the player must circle around the truth, experiencing it from many different angles, each angle being a single instantiation of the game. Only after the player has seen it from enough angles can he assemble a complete mental image of the truth of the game. . . .[T]his inductive process of assembling a mental

♣ As noted earlier, a microworld is a name for a type of simplified simulation most suitable for younger students..

> image of the truth of the game, this is fundamentally an unconscious process. . . . This suggests that the game is really a form of indirect communication. (Crawford, 1996b)

Rather than being a conscious and explicit process, learning during gameplaying occurs indirectly and as a result of the player's repeated attempts to shift the gameworld into a certain state. Because the players of a digital game are not told the rules that govern the gameworld they must learn them through induction, based upon what they observe (Greenfield, 1984). Each time players make the attempt to accomplish their goal they experience a different instance of the game, and through these experiences they begin to form an understanding of the relations and mechanisms that make specific actions have specific consequences within the gameworld (Crawford, 1996b; Juul, 1999). This is as much to say that they: internalise the gameworld's rules (Kücklich, 2001; Papert, 1992); construct a mental model of its dynamic structure (Brody, 1993; Crawford, 1995e; Manovich, 1998; Murray & Jenkins, 1999; Pearce, 2002b), and that they understand it intuitively and qualitatively (Costikyan, 1988; Dede, Salzman & Loftin, 1996b; Papert, 1980; Sigmund, 1993). Players do all this through necessity since in order to win they must be able to predict the consequences of each decision that they make (Friedman, 2001; Rouse, 2000), and as a game is played repeatedly players' mental-models of the gameworld's dynamic structure become increasingly accurate until finally the game no longer presents a challenge. Of course, some games (such as bridge, chess, and go) are so complex that people could (and do) dedicate their lives to understanding them.

An example of the sort of complex dynamic structures that digital games can challenge their players to understand is provided by *Pac-Man*. For those of you who do not recall, in the arcade game *Pac-Man* a small, pizza-shaped mouth (i.e. Pac-Man) traverses a maze, eating dots and energiser pills, and avoiding ghosts. There are four ghosts, and they chase Pac-Man through the maze and eat him if they catch him, but he can also eat them for a short time after eating an energiser pill. Toru Iwatani, the designer of *Pac Man*, notes that the most difficult part of the game to design was:

> The algorithm for the four ghosts who are dire enemies of the Pac Man – getting all the movements lined up correctly. It was tricky because the monster movements are quite complex. This is the heart of the game. I wanted each ghostly enemy to have a specific character and its own particular movements, so they weren't all just chasing after Pac Man in single file, which would have been tiresome and flat. One of them, the red one called Blinky, did chase directly after Pac Man. The second ghost is positioned at a point a few dots in front of Pac Man's mouth. That is his position. If Pac Man is in the centre then Monster A and Monster B are equidistant from him, but each moves independently almost "sandwiching" him. The other ghosts move more at random. That way they get closer to Pac Man in a natural way. When a human being is constantly under attack like this, he becomes discouraged. So we developed the wave-patterned attack-attack then disperse; as time goes by the ghosts regroup and attack again. Gradually the peaks and valleys in the curve of the wave become less pronounced so that the ghosts attack more frequently. (Lammers, 1986)

Discussing the complexities of the ghost behaviours in Pac-Man, Greenfield (1984) notes that "This situation may sound a bit like chess, in which each piece has its own allowed behaviour. But in Pac-Man, as in other video games, no one tells the player the rules governing each monster's behaviour; these rules must be induced from observation" (p. 110).

Despite what has been said above, the idea that gameplayers learn anything at all (let alone anything of educational value) remains a controversial one within educational contexts. Papert (1992) notes, for example, that:

> School would have parents – who honestly don't know how to interpret their children's obvious love affair with video games – believe that children love them and dislike their homework because the first is easy and the second is hard. In reality, the reverse is more often true. Any adult who thinks these games are easy need only sit down and try to master one. Most are hard, with complex information – as well as techniques – to be mastered, the information often much more difficult and time consuming to master than the technique. (p. 4)

Illustrating that these attitudes are deeply felt, Greenfield (1984) made identical comments almost a decade earlier:

> . . . there is much more to the games than hand-eye coordination. In fact, not only are they complex, they incorporate types of complexity that are impossible with conventional games. I am convinced that many of the people who criticize the games would not be able to play them themselves. (p. 107)

The reason that the connection of gameplaying with learning has remained so controversial is that the term *learning* is frequently used, not to denote "every form of cognitive acquisition" (Piaget, 1970/1983, p. 112), but rather to denote *the acquisition of educationally desirable information and skills*, and a deep chasm may exist between these two meanings. So for example, Christopher Dede (a well known *pro*ponent of educational games) notes that:

> Access to desirable high-level magical powers often requires developing a detailed mastery of a MUD's [i.e multi-user domain's] lore and the rules collectively developed by its inhabitants – a process that can be both time-consuming and largely uncorrelated with learning. (Dede, 1995)

and this statement makes sense because what Dede means by *learning* in this context is the acquisition of *educationally valuable* information and skills. The tension between the Piagetian and educational uses of the term *learning* is similarly evidenced by the continuing debate regarding whether digital-game playing promotes violence. Digital games were recently denied the protection of the First Amendment to the U.S. constitution (which protects freedom of speech) on the grounds that they do "not contain enough particularized expression to be judged as a form of speech and that any communication or expression that does occur through their use is purely inconsequential" (Limbaugh, 2002), and if games are not communicating anything consequential then it does seem problematic that anything consequential might be learned from playing them. The reason that attempts were being made to secure protection for video games under the First Amendment in the first place was, however, in response to an attempt to restrict their usage on the grounds that gameplayers learn violent behaviours and violent attitudes[♣], and such learning would seem to be particularly consequential.

Since the type of learning that games facilitate – i.e. the development of qualitative understandings discussed earlier – is only implicitly valued within educational contexts and is not easily measured or evaluated (Game-Research.com, 2002; McFarlane et al., 2002), it is unsurprising that many parents and teachers find controversial the idea that gameplaying can facilitate learning (even despite the fact that many studies have shown games to be as good as, or even superior to, classroom teaching (cf. McGrenere, 1996; Randel, Morris, Wetzel, & Whitehall, 1992, as cited in McDonald & Hannafin , 2003)). Games do, however, possess another feature that makes them educationally useful and

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[♣] Incidentally, despite over twenty years of research into the issue, the results of studies aimed at discovering if violent games promoted violence have collectively been inconclusive (Freedman, 2001; Durkin & Aisbett, 1999; IDSA, 2001; Ivory, 2001).

whose existence is not questioned by anyone, and this feature is that they are intrinsically motivating.

"One of the biggest problems in all formal learning . . . is keeping students motivated" (Prensky, 2002b), since an essential feature of educational activities is that the user's motivation for engaging in them is external. While ideally students would be motivated to learn the material presented to them by their interest in it, in actual fact students often do not see school tasks as either meaningful or authentic and their only motivation to perform them (and the only value they place in them) tends to be as a result of external rewards and punishments (Ames, 1992; Dewey, 1900/1956; Inbar & Stoll, 1970; Prensky, 2002b; Rieber, Luke & Smith, 1998; Ruenzel, 2000). Thus, while a few of the more interested students in a class will reflect upon the material being taught and apply it to real-world situations, most students will rote learn it for the short-term benefits of testing and then quickly forget it after exams are over (Foreman, 2003).

In contrast with the external motivation prompting much educational activity, game playing is internally motivated and constitutes an end-in-itself (Aguilera & Mendiz, 2003; Callois, 1961; Inbar & Stoll, 1970; Weisler & McCall, 1976). Whilst within school classrooms (and edutainment) only an artificial connection exists between what is learned and the activities that the student actually engages in, what is learned within a gameworld is relevant and meaningful in the context of the game itself (Papert, 1980), and thus players take genuine pride in advancing through a game because they have developed a skill and do not need to be coaxed through using external encouragement (Brody, 1993).

There is a belief amongst many educators that education should not be fun, or at least, that its lack of fun is not a sign of any problem (Okran, 2003; Prensky, 2002b). Some educators take an even stronger position: "When education and entertainment are brought together under the same roof" says Shortland (1987) for example, "education will be the loser" (p. 213). Now, games are deliberately designed to be fun to play – so much fun in fact that they are often referred to as (or criticised for being) addictive (Brody, 1993; Greenfield, 1984; Meier, 2000; Papert, 1992; Pearce, 1998) – and thus they might easily be seen as an inappropriate educational tool. Greenfield (1984), however, proposes that "perhaps the most valuable thing we can learn is not how to make the games less addictive, but how to make other learning experiences, particularly school, more so" (p. 123), and this sentiment is repeated by Papert (1998a), who notes that "[M]embers of the teaching profession or parents . . . become green with envy when they see the energy children pour into computer games" (p. 1), and also by Stapleton and Taylor (2002), who remark that "Computer games seem to captivate the imagination and attention of contemporary teenagers. If only the energy, motivation, fun and exhilaration they enjoy from playing games on their PC, or on consoles . . . could be captured in learning physics!"

The great advantage of constituting educationally significant information in the form of a game is that players' desire to win the game can provide them with a compelling reason to want to absorb this information – information that they might otherwise perceive they had no use for (Brody, 1993; Kirriemuir, 2002b; Torres & Macedo, 2000). Of course, the use of the motivational quality of gameplay in the service of education must always be a somewhat self-contradictory affair: play is essentially an unproductive and unforced activity whereas education is the opposite of these things and thus to the degree that students feel that they *have to* play a game they are less likely to find such gameplaying to be self-motivating (cf. Pittman & Boggiano, 1992). Nonetheless, in the context of conventional education where there are often few or no sources of internal motivation for engaging in schoolwork, any educational environment that offers even minimal internal motivation represents a step in the right direction.

Earlier it was noted that gameplayers pay attention to a game's structure (i.e. processes) rather than its content (i.e. data) and thus process-intensive games facilitate learning in a manner that accords with the player's natural disposition while data-intensive games do not. Because most educational game designers possess an instructivist outlook (or else are designing for parents and teachers whom they believe have such an outlook), however, the vast majority of educational games are data-intensive rather than process-intensive. Nonetheless, the Education Arcade project♣, a partnership between the Massachusetts Institute of Technology (MIT) Comparative Media Studies Department and Microsoft Corporation, has produced a number of prototype process-intensive education games, and two of these will be briefly discussed here. The first of these games is called *Supercharged*, has been designed for both PCs and consoles, and is a

♣ Retrieved February 11, 2004, from http://www.educationarcade.org/gtt/proto.html. See also Holland, Jenkins & Squire, 2003.

puzzle/action game in which the player races "through 3D mazes consisting of electrostatic forces, magnetic fields, and electric fields" by using their knowledge of the properties of charged particles (Games-To-Teach, 2000a). Another of these games is called *Replicate*, has been designed for consoles, and is an action/racer game in which the player uses their knowledge of virology and immunology in order to "Play a virus and replicate inside a host organism". The player of *Replicate* must migrate "through the circulation, entering target cells, and replicating inside them" and "Outwit the full force of the human immune response and maintain a level of viremia that allows you to be transmitted, yet not kill your host, upon whom you depend for survival" (Games-To-Teach, 2000a). Screenshots of both games are shown in Figure 21.

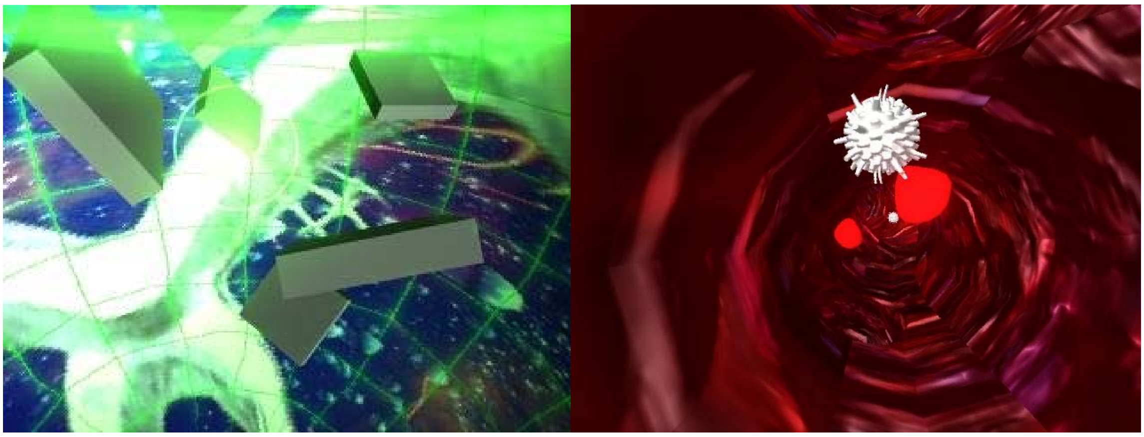

**FIGURE 21** – Screenshots from the Games-To-Teach prototype games *Supercharged* and *Replicate*♠.

From the promotional quotes and images alone it is clear that these games are not edutainment: their educational content is integrated with their gameplay and their

♠ Retrieved February 11, 2004, from http://www.educationarcade.org/gtt/proto.html.

gameplay is highly interactive. These games are not, however, science-simulation (i.e. SciSim) games either. This remark has been made, not because the Education Arcade project claims that their games are SciSim games, but rather because the distinction between SciSim games and process-intensive educational games may easily be overlooked, and because this is the first opportune moment to clarify the issue.

Games such as *Supercharged* and *Replicate* require their players to possess some pre-existing knowledge of electrostatics or virology before they can play, and no such pre-existing knowledge may be presumed of laypeople. Similarly, games such as *SimEarth* and *SimLife* require their players to possess some basic knowledge of climatology and evolutionary biology, and thus many people respond to them more as educational games than as entertaining games. That many players of *SimEarth* and *SimLife* do not possess sufficient knowledge of climatology and evolutionary biology is an important reason why these games have not been successful, and one would likewise expect that *Supercharged* and *Replicate* would not be popular games if targeted at a non-expert (using the term *expert* somewhat loosely) user group. In order to create a *popular* SciSim game one must assume, just as conventional game-designers assume, that one's players will not read any rules or instructions and that they will not know anything about how to play the game prior to their first contact with it. Unlike educational game designers, SciSim game designers cannot rely upon their players having recently completed high school biology up to the 10$^{th}$ grade, or assume that their players will be instructed to play the game whether they wish to or not. The task of the SciSim game designer is thus quite different to the task of the educational game designer. The converse is also true. Realism (as was observed in Chapter Three) can be boring, while fantasy can be fun, and realism in one area of a game must be matched with realism in other areas of a game or else the gameplay will be inconsistent. SciSim games must thus sacrifice realism for entertainment, but in doing so they will sacrifice what for educators is most desirable, namely, educational content:

> Some teachers have used popular games like SimCity and Civilization in classes, but education specialists say that such programs, while useful, ultimately fall short. "They're good games, but they're inherently weak on education," said Eric Klopfer, an assistant professor of science, education and educational technology at the Massachusetts Institute of Technology. "They can be harnessed for education, but they weren't designed from the ground up for education." (Larson, 2004)

Process-intensive educational games and SciSim games are closely related, but ultimately distinct software artifacts, and it is only when game designers are clear about the differences between the two that they can successfully create one or the other.

# The Creation of Educational Games

Whilst it is outside the scope of this thesis to present a detailed discussion of educational game design, nonetheless a number of different authors have proposed ideas that are relevant to this topic and these ideas are discussed below.

## Malone's Theory of Intrinsically Motivating Instruction

The problem of how to design digital games to be learning environments was first addressed by Malone (1981) and his analysis of the problem remains relevant and useful over twenty years later. Malone proposed that in order to create *educational* games that possessed the motivating quality of *entertaining* games, one had first to discover what makes the latter games so motivating. Malone identified three aspects to entertaining digital games that make them intrinsically motivating: challenge, fantasy, and curiosity. As we shall see, Malone's discussion of how these aspects should be dealt with when designing learning environments is in close harmony with much that has been said by later researchers whose primary concern was entertainment.

One aspect of games that makes them intrinsically motivating is the challenge they present to players, and this challenge varies according to the nature of the game's goals and the difficulty of accomplishing these goals. With respect to goals, these may be fixed (i.e. goals predetermined by cultural convention) or emergent (i.e. goals that become apparent as the game environment is interacted with), but either way they must be personally meaningful to the player if they are to become the player's goals. Now, since learning *per se* is unlikely to be a personally meaningful goal for most players, whatever learning players do engage in must be a means to achieving the game's goal and not the goal itself, and thus educational content must be integrated with game structure. With respect to level of difficulty, in order for a game to be challenging its ultimate outcome must always remain uncertain, and this must be true regardless of the level of skill of the player. Players must thus be able to adjust the level of difficulty of the game to suit their own abilities, they should be able to choose from amongst a variety of qualitatively different types of challenge, and the game should provide clear criteria and informative feedback so players can judge and improve their performances.

A fantasy-inducing environment is one that contains images of things not usually present to the senses or within the actual experience of the user. Fantasies can be of two types: intrinsic and extrinsic. Extrinsic fantasies are those where the progress of the fantasy depends upon the use of the skill learned in the game, but not vice versa, whereas with intrinsic fantasies the relationship works both ways. So for example, a driving game that requires the player to solve maths problems at toll booths in order to keep driving uses an extrinsic fantasy, since while the player cannot keep driving without using maths they can use maths without driving. By contrast, a driving game that requires the player to learn the physical dynamics of the automobile in order to win a car race uses an intrinsic fantasy, since not only can the player not progress without learning the car's physical dynamics but the player cannot learn the car's physical dynamics without progressing. Malone (1981) proposed that learning environments using intrinsic fantasies are more interesting, more instructional, and more motivational than are those using extrinsic fantasies, and others express a similar point-of-view:

> A challenge for designers of educational games is to find ways to fuse educational content with the gameplay, so that students are solving authentic problems, engaging in meaningful scientific, mathematic, or engineering practices, thinking creatively within these domains, and communicating their ideas expressively. (Games-to-Teach, 2000b)

> And the educational side, it's not something that you tack on, it's got to be fundamental to the design. . . . If the entire design is true to that, it might be educational at some deep level even though you play it for hours and never think it is educational even once. (Wright, 2000, p. 468)

Malone also recognized, however, that learning environments using extrinsic fantasies are easy to design (cf. Rieber, Luke & Smith, 1998), and this factor of ease is undoubtedly in part responsible for the relative abundance of data-intensive educational games.

Malone (1981) proposed that there are two different types of curiosity: sensory curiosity and cognitive curiosity.  Cognitive curiosity is the desire to improve one's knowledge structures related to the environment and to give these structures completeness, consistency, and parsimony.  Sensory curiosity, by contrast, is evoked by the attention attracting value of changes to the visible, audible, or other sensory aspects of the environment.  Maximum curiosity is aroused when the level of informational complexity that a learning environment provides is neither too complicated nor too simple, but is rather optimal.  As is the case with challenges, therefore, the way to ensure an optimal level of complexity is to adjust this level for each individual user or to allow users to adjust it for themselves.

These distinctions that Malone makes within each category (i.e. between fixed and emergent goals, between intrinsic and extrinsic fantasies, and between sensory and cognitive curiosity) all possess parallels in distinctions made within previous chapters of this thesis.  The distinction made between fixed goals and emergent goals relates directly to the distinction made between games and toys (Crawford, 1982; Wright, 2000): games possess fixed goals for the player to accomplish while toys do not, and the users of a toy have the freedom to decide what goals they will attempt to accomplish.  The distinction made between extrinsic and intrinsic fantasies relates directly to the distinction made between edutainment and process-intensive educational games: edutainments use extrinsic fantasies whereas process-intensive educational games use intrinsic fantasies. The distinction made between sensory and cognitive curiosity relates directly to the distinction made between the look and feel components of immersion: the look of an immersive environment generates sensory curiosity whereas its feel generates cognitive curiosity.

## Csikszentmihalyi's Concept of Flow

One body of research that is often mentioned in the context of educational game design is Mihalyi Csikszentmihalyi's work (cf. Csikszentmihalyi, 1990) on psychologically optimal experiences. Csikszentmihalyi proposed that a person enjoys those activities that create an experience that he labelled as *flow*, an experience that has eight major components:

1. **Clear goals and immediately feedback**. Most optimal experiences occur in situations that are goal-directed, bound by rules, and that provide us with clear feedback regarding our performance.

2. **Personal skills well suited to given challenges**. Optimal experiences occur when we are confronted with some form of challenge and where we possess the skills necessary to meet that challenge. When a challenge grows too great for us we feel anxiety, while when a challenge is not great enough we experience boredom.

3. **Merger of action and awareness**. The term *flow* describes a state of seemingly effortless movement. Action becomes spontaneous, almost automatic, and we do not perceive ourselves to be separate from the movements that we make.

4. **Concentration on the task at hand**. Enjoyable activities require a complete focusing of attention such that everyday existence fades from consciousness. Because enjoyable activities possess clearly structured demands, when engaged in them only a select range of information need be allowed into awareness. Within daily life, by contrast, we are confronted with numerous competing demands upon our attention.

5. **A sense of potential control**. Flow experiences involve a sense of control, or conversely they lack the sense of worry about losing control that is typical during many mundane situations. What is experienced is not so much the *actuality* of control but only the *possibility* of control, and enjoyment comes from attempting to exercise this control and not simply from having it. Activities that produce flow experiences are so constituted that they allow those engaged to continuously improve their skills so that their degree of control constantly increases.

6. **A loss of self-consciousness**. During optimal experiences we experience a loss of the sense of being separate from our environment. Rather, we are entirely caught up in the activity that we are engaged in and we have no remaining capacity to pay attention to our egoic self.

**7.** **An altered sense of time**. During optimal experiences time no longer seems to pass the way it ordinarily does, instead passing much faster or occasionally (such as during particularly time-critical activities) much slower.

**8.** **Experience that becomes an end-in-itself**. Optimal experiences occur when we are engaged in an activity that for us constitutes an end-in-itself, even if to begin with we were motivated to engage in this activity by extrinsic factors.

The relevance to game design of Csikszentmihalyi's ideas is that these eight components of flow are the basic components of a good game. A good game, that is, is one that presents the player with clear goals that they desire to accomplish (1,8), is highly interactive (1,3), possesses just the right level of difficulty and is able to provide a challenge as the player improves (2,5), and is highly immersive (4,6,7).

## Miller's Seven Kisses of Death

In an article entitled *Designing for Kids: Infusions of Life, Kisses of Death*, Carolyn Miller (2000) noted that:

> There is one totally inescapable problem inherent in designing projects for children: no matter how youthful we may be, either in appearance or in spirit, the harsh truth is we are no longer members of this particular demographic group. We are grown-ups; they are kids; there is a great chasm of years between us. (Miller, 2000)

Because of this "chasm of years", adults designing entertainment software for kids tend to maintain beliefs regarding what kids want that are not accurate and that if implemented, will alienate rather than attract the target audience. Miller labeled these beliefs the “seven kisses of death”, and they are described below.

**Death kiss 1: Kids love anything sweet**. While children do appreciate sweet foods, they do not appreciate sweet entertainment. They do not enjoy depictions of worlds without conflict where everyone is kind, gentle, and loving. They are curious about scary and disturbing things and their lives (and thus interests) are as full of conflicts as are the lives of adults. Their taste, moreover, is what many adults think of as bad taste. Kids like toilet humour, for example.

**Death kiss 2: Give 'em what's good for 'em**. Edutainment software products in particular have a tendency to preach, lecture, and talk down to the kids who use them. They also have a medicinal approach to presenting their content and aim to give kids what is good for them whether they like it or not. Children, however, “prefer dessert to vegetables” and require frequent rewards if they are to be persuaded to perform educational tasks within a game.

**Death kiss 3: You gotta amuse 'em**. This kiss of death might also be labeled “just give kids what they want” and is essentially the *lowest common denominator* [LCD] approach described in Chapter Two. As discussed in that chapter, while it is true that the LCD approach does give everyone a little bit of what they want, it gives no one what they *really* want. Certainly, kids (and indeed, people of all ages) desire entertainment, yet they also desire interesting and substantial content. The most successful children’s entertainment thus incorporates realism and serious ideas.

**Death kiss 4: Always play it safe!** Through their desire to avoid sex, violence, and controversy, the makers of educationally oriented children's software also avoid excitement, action, and jeopardy. It is noteworthy that this mistake is not made by the makers of entertainment software as a great many entertainment titles are packed full of sex, violence and controversy.

**Death kiss 5: All kids are created equal**. Children a few years apart in age have widely different needs, tastes, and abilities to understand ideas and to perform tasks. Similarly (though this is not a point that Miller makes herself) when it comes to games, boys and girls too give evidence of different needs and tastes. Because of these differences amongst users, therefore, it is a mistake to attempt 'one-size-fits-all' game design and a more successful approach is to design for a particular user group.

**Death kiss 6: Explain everything**. Educational software designers have a tendency to overuse words in the attempt to make sure that their users understand what is going on. As we have seen, however, gameplayers will frequently not read instructions and will begin playing even if they don't completely understand what to do, so just because text is included in a game does not mean it will be read. The maxim of game designers should be "Show, don't tell" (Falstein, 1996), since, as discussed in Chapter Two, apart from when dealing with abstractions, images are superior to words as a means of conveying information.

**Death kiss 7: Be sure your characters are wholesome**. This approach has much in common with death kisses 2 and 4, but relates strictly to game characters. Educational game designers (and also the designers of much interactive entertainment) have a tendency to create stereotypical and homogeneous game characters, either making them all nice and attractive, or else making good ones who look nice and bad ones who look nasty. A better approach would be to not have strictly good or bad characters and to make each one a rounded individual.

While Miller proposes that it is the "chasm of years" between adults and kids that is responsible for these "design blunders", perhaps they are not blunders at all. It is noteworthy that all of the games and software artefacts that she discusses in her article are educational, and since educational games are purchased by adults rather than children they are most likely designed with the adult purchasers in mind. When game designers make games sickly sweet and wholesome, therefore, this is probably because they *do* know what parents want for their children, rather than because they *do not* know what children want. This is all the more likely because game designers do not make Miller's design blunders when designing *entertaining* games for kids. The lesson to be learned from Miller's (2000) article is thus that it is a mistake to design games for anyone apart from the end-user.

# Summary

The purpose of this chapter was to determine both in what ways educational games can facilitate the construction of scientific knowledge, and what attributes of games make them enjoyable to play. The answer to both these questions was found to depend upon what sort of educational game was being discussed. Data-intensive educational games (edutainments) were found neither to facilitate knowledge construction nor to be enjoyable. Process-intensive educational games, by contrast, were found to do both these things and were identified as being similar to educational simulations in that they are based upon mathematical models. Process-intensive educational games are able to facilitate learning both because they engage their players in intrinsically motivating activities and because the process of interacting with a gameworld leads the player to internalise the gameworld's rules. Such games are enjoyable to play so long as: they present the player with clear and desirable goals; they are interactive and immersive; their educational content is integrated within their structure; they provide a challenge to both beginners and experts; and so long as they are tailored to the needs and desires of those who play them, rather than of those who purchase them.

*. . . it was from poets and popularizers rather than from astronomers that most people in the sixteenth and seventeenth century, as today, learned about the universe.*

*(Kuhn, 1957, p. 190).*

# CHAPTER SEVEN
# Conclusion

During the introduction to this thesis it was proposed that scientific culture is not a popular culture and that it is in the interest of both scientists and society that science should be popular. It was also proposed that science could be widely popular if it were communicated in an intrinsically enjoyable way, and it was hypothesised that digital games could make science intrinsically enjoyable. In order to test this hypothesis, the attributes that make scientific simulations and games useful for scientists and students were investigated, as were the attributes of digital games that make them enjoyable to play. It is the aim of this final chapter to summarise what has already been discovered, to show to what degree digital games can communicate science in an intrinsically enjoyable way, and to discuss the consequences and usefulness of the present research for the theory and practice of science communication.

## Can digital games make science intrinsically enjoyable?

Over the course of the previous chapters a number of attributes of simulations and games have been discovered that make them effective in facilitating scientific knowledge construction, and similarly a number of attributes of games have been discovered that make them enjoyable to play. While there are differences between these two groups of attributes there are also some strong similarities. The re-creation of reality, the simulation of complex systems, visualisation and interactivity, engagement of the user in the practice of science, and construction and collaboration are attributes that feature prominently in both groups.

### The Re-creation of Reality

The majority of systems that scientists study are not readily accessible to human beings within their daily lives. Some of these systems are inaccessible because of their size: they are too large or small to be easily observed or experimented upon. Others of these systems are inaccessible because they are too far away, or because they travel too fast. Still others of these systems are inaccessible because studying them is dangerous or expensive. Regardless of the way in which scientifically interesting systems are inaccessible, the end result is that scientists are not able to effectively study them. Simulations – computer-based mathematical models – are able to re-create such scientifically interesting systems in a form that provides their users with complete control and complete safety.

This same ability to re-create reality makes games attractive to players. Gameplayers desire to live life according to new rules and to do things that are difficult or impossible in real life. Many digital games engage players in activities would be extremely dangerous (e.g. fighting), expensive (e.g. flying an aeroplane), or difficult (e.g. playing in a football championship) if conducted in real life, and many games also allow the player to do things that are actually impossible, such as controlling a family of people (as in *The Sims*) or controlling an entire city (as in *SimCity*), not to mention providing them with immortality (a feature of almost all games). Additionally, a great many games 're-create' a *fantasy* reality, and this ability to freely mix fantasy and reality and to provide players with hyper-real experiences is another of the attributes of digital games that make them so enjoyable.

If digital games based upon scientific simulations (i.e. SciSim games) were to be created then the 'fantasy' environments discovered and created by scientists would become playgrounds for gameplayers. Gameplayers desire and seek out new realities – environments governed by new rules – and scientists create and discover such realities. The very fact that the realities studied by scientists are so inaccessible *makes them interesting* as the bases for games, and thus with respect to the re-creation of reality digital games can make science intrinsically enjoyable.

## Complex Systems

Complex systems are made up of large numbers of elements behaving in an organized fashion and they exhibit emergent properties, meaning that their overall behaviour may not be predicted solely from an understanding of the parts that make them up. Despite the fact that complex systems are the most numerous systems that people come into contact with, for most of science's history scientists have studied simple systems, and this is because complex systems require complex models, because such models cannot be used to generate predictions without significant computational power, and because such power did not exist prior to the development of computers. Once computers were developed scientists used them to model complex systems, and in the process they created simulations.

The ability of simulations to model complex systems is as important to gameplayers as it is to scientists, and this is because games based upon complex systems are more replayable and offer more interesting gameplay than those based upon anticipatory systems. The user of data-intensive games (games based upon anticipatory systems) may only wander down the same few pre-specified paths again and again, and the only puzzles and problems they can solve are those previously thought up by the game-designer. Moreover, when these problems have been solved once they have been solved forever, and thus data-intensive games do not afford much replayability. Replayability being a fundamental characteristic of good games, data-intensive games are thus not especially good games. Process-intensive games, by contrast, *are* highly replayable since they afford their players the possibility of freely exploring large, rich, gameworlds, and because of the complex nature of their gameworlds digital games present their players with complex and emergent challenges. Such challenges are susceptible to multiple solutions, their solution requires the player to make many interesting decisions, their nature may to some extent be determined by the player, and they may be met by the player in a personalised and idiosyncratic manner. The ability to model complex systems is thus as important to making simulation-based games enjoyable for players as it is to making simulations useful for scientists.

## Interaction and Visualisation

By virtue of their ability to enable real-time interactivity and to visualise data, simulations allow their users to gain quasi-direct experiences of systems, to act upon systems, and to visually perceive the results of their actions. As a consequence of these experiences and actions simulation users develop qualitative understandings of the simulated system's dynamic behaviour, and these understandings can in turn challenge their existing alternative conceptions and can provide foundations for quantitative (i.e. formal and abstract-conceptual) understandings.

The combination of interactivity and visualisation is equally valuable for gameplayers, providing them with a gameplaying experience that can immerse both their senses and their cognition. The more immersive a game is the more able are its players to forget that they are playing a game and the more they come to treat the gameworld as a new reality. Immersiveness is a fundamental characteristic of good games, and thus the interactivity and visualisation afforded by simulations are both useful for scientists *and* enjoyable for gameplayers.

## Science Practice

Scientific knowledge consists of both knowledge *about* systems and knowledge of *how to* investigate them, and this latter *how-to* knowledge cannot be gained solely or even primarily from reading about science or watching scientists, but must rather be gained from actually practising science. Simulations assist scientists in this practise not only by re-creating and concretizing complex realities but also by acting as scientific tools to be used in the solution of scientific puzzles.

Gameplayers, like scientists, are motivated by the desire to solve problems and puzzles and this desire is so strong that games are frequently labelled as addictive. The actual process of puzzle-solving takes place in the same way during both scientific work and gameplaying, involving many cycles of action, observation, reflection, and theorising. Gameplayers, that is, act upon the gameworld with the intention of accomplishing their goals, they observe the effects these actions have had, they reflect upon the divergence between what they tried to make happen and what did actually happen, and based upon these reflections they formulate and implement new strategies (i.e. theories of how to win). Both gameplayers and scientists must feel assured that a solution to the puzzle they are working on actually exists since motivation for puzzle-solving in either context is contingent upon the puzzle neither being trivially easy or impossible difficult. Additionally, both gameplayers and scientists gain motivation to explore the alien worlds that they are interacting with from the knowledge that they can solve a particular puzzle, if only they understand these worlds well enough.

## Construction and Collaboration

When scientists use simulations they frequently engage in simulation construction. This is almost essential since simulations are scientific theories and so to the degree that they are unable to accurately predict data they must be modified. Science students too can engage in simulation construction and can thereby improve their scientific understandings. The process of simulation design requires the acquisition and comprehension of scientific information, the articulation of and reflection upon existing knowledge, and the integration of scientific and programming knowledge. This process also encourages collaboration amongst designers which in turn facilitates knowledge construction since as designers work together they share their skills and review and critique each other's work.

Now, just as simulation construction (and the collaboration that occurs around it) can facilitate scientific-knowledge construction, so too in the world of digital games the ability to modify games and the socialisation that occurs around gameplaying constitute important motivations for playing them. Game designers release middleware game construction tools along with their games because they know that many players enjoy construction as much as they enjoy playing the game itself, and because the modifications that these players create will provide enjoyment for many other players also. Similarly, game designers create multiplayer games and facilitate socialisation around games because players devoted to a game wish to form teams, discuss strategies, and swap modifications with each other. Construction and collaboration are thus simultaneously important to scientists and science students as means of facilitating learning and important to gameplayers as means of facilitating enjoyment.

The five attributes of simulations and games discussed above are not *all* of the attributes that make simulations useful, nor *all* of the attributes that make digital games enjoyable. Moreover, it is somewhat misleading to even call them attributes: *categories of attributes* would probably be a better term. These categories do encompass what has been shown to be *essential* to making simulations useful and games enjoyable, however, and thus upon the basis of the above summary it is proposed here that, fundamentally, digital games based upon scientific simulations are capable of making the construction of scientific knowledge intrinsically enjoyable. This is the major finding of the thesis. Having arrived at this discovery, however, it now becomes pertinent to ask:

1. what significance does this finding have for the theory and practice of science communication?
2. through what channels can this finding influence the development of a stronger popular scientific culture?
3. how can the research leading to this discovery be used to assist concretely in the development of SciSim games?

## 1. SciSim games and science communication

As was established in Chapter Two, *science communication* is not simply an abstract term denoting the transmission of scientific information, it is also a specific term denoting a body of theory and practical activity concerned with improving dialogue between scientists and a variety of ‘publics’. Improvements to this dialogue, it was suggested, can confer certain benefits upon both scientists and the public, and given that science communication efforts are frequently labelled as ‘sensationalist’ there is clearly room for some improvement. These things being the case, therefore, how does the knowledge that SciSim games are able to communicate what is essential to science in an interesting and enjoyable manner relate to the theory and practice of science communication?

Considering first the issue of ‘the public’, while popular science books, newspaper articles, lectures and television documentaries communicate scientific ideas to many people, these are primarily people who are already interested in science - they are ‘the converted’ - and those people who think of science as unattractive, uninteresting or confusing will not consume such media. Digital games, however, can communicate scientific experiences indirectly and covertly and can thus communicate science to new groups of users.

Digital games are capable of communicating science covertly because the player of a game is not trying to learn anything. Rather, they are simply trying to win the game and thus they are not concerned with the game's content but only with its structure. A game’s structure (i.e. its gameplay) is not, however, something that is capable of being ‘scientific’ (in the sense that laypeople use this term) since it is nonsymbolic and thus does not involve jargon or equations. That a game is based upon a scientific simulation may become apparent to users over time, or it may never become apparent, but either way those users will still have been exposed to its structure and will have developed a qualitative understanding of this structure that they can make use of in the future. So for example, having played a digital game based upon a simulation of cellular division a player will (ideally) *not* have been exposed to terms such as *mitosis*, *meiosis*, *chromosome*, *chromatid*, or even *DNA*, yet they will nonetheless have developed meanings for such terms, and were they later on to be exposed to these terms from some other source they would quickly be able to understand them. By virtue of their ability to covertly communicate information, therefore, digital games are a medium through which many new publics may be exposed to science.

Considering next the issue of dialogue, it will be recalled from Chapter Two that:

- symbolic communication is only possible to the degree that each communicant 'means' the same thing when they use a given word or phrase.
- during communication between scientists and the public such commonality of meaning frequently does not exist, and thus that
- dialogue between scientists and the public is hampered even when each group genuinely wishes to understand the other.

Communication using digital games takes a qualitatively different form from communication using words and pictures alone, however, and consequently dialogue using digital games will take a qualitatively different form than does symbolically-mediated dialogue.

It has previously been shown that the users of simulations and games are able to affect the structure of these media in ways that are unavailable to the users of conventional media. While the users of popular science books, newspaper articles and television documentaries passively absorb scientific information, the users of scientific simulation-games are (at least potentially) able to construct new versions of these games and to make these new game versions available to the original game-designers. Now, when scientific dialogue is engaged in using simulation games there is no danger of miscommunication because unlike words (which *refer* to stored sense-based experiences that might differ from one person to the next), simulations are *productive* of new sense-based experiences which will be essentially the same for every person who uses the simulation. Because of the homogeneity of experience that simulations produce, therefore, it is possible for scientists and the players of SciSim games to engage in an enhanced form of scientific dialogue, and thus for SciSim games to facilitate improved science communication.

Currently this game-mediated dialogue does not occur to any extent because so few SciSim games exist, yet the manner in which this dialogue could take place need be in no ways different to the manner within which games are currently modified by players (as was described in Chapter Three). Following the current convention, a SciSim game would be released in such a form that sufficiently interested users could 'tweak' the model underlying the simulation and then post their altered version up onto the web. In this way it would be possible for interested users to improve upon a game (whether this meant to make it more realistic or more productive of enjoyable gameplay), and they could also use game simulations in ways that were never envisaged by their creators (such as by creating *Machinima*, (see p. 94)). Of course, only a small proportion of the players of any given game would have the time, interest or expertise necessary to alter a game in scientifically interesting ways, and thus SciSim games are not envisaged here as a panacea for the problem of dialogue between scientists and the public. They are a new medium with new strengths and new deficits, and one that may (and *should*) be added to the collection of tools used by science communicators.

Considering finally the issue of sensationalism and science, as was discussed in Chapter Two it is difficult to communicate what is most essential to and interesting about science (i.e. the practice of science, and scientific models) to laypeople using conventional media, and this is because conventional media are symbolic and iconic, but not interactive. Scientific practice requires interactivity between the scientist and the reality which they study and scientific models can be properly appreciated only when they can be interacted with, but conventional media are unable to facilitate interaction. Science communicators using conventional media must therefore make science interesting in other ways: by communicating sensational scientific facts, by telling the life stories of scientists, and by confining themselves to those areas of science which possess an intrinsic appeal (e.g. dinosaurs).

Now, there is nothing 'wrong' with communicating science in these ways, and contemporary science communication would be poorer if these methods were not utilized, yet in the absence of some other means of communicating what is essential to science these efforts provide a distorted and less-than-accurate picture of what science is, and what the practice of science involves. It has been shown within this thesis, however, that digital games are able to communicate what is essential to science in an enjoyable manner and thus science communication using SciSim games is able to do without the sensationalism frequently employed when science is communicated using books, newspapers and television documentaries. Digital games not only allow (indeed, require) their players to be active, but they also frequently require their players to interact with a reality whose rules differ from those governing the familiar spatio-temporal realm that humans inhabit, and thus games are seemingly tailor-made for communicating the unfamiliar realities studied by scientists. Similarly, while the models that scientists construct of these realities are incomprehensible to most people when expressed symbolically (i.e. as equations), they make immediate sense to people when expressed visually and when they may be interacted with physically. Indeed, scientists themselves make use of the visualizing and interactive aspects of simulations to assist them to understand complex systems and the microscopic and macroscopic realities of the atom and the galaxy. The practice of science communication, thus, can be improved by making use of digital games to communicate what is essential to science.

## 2. Games, Science, Culture

The knowledge that digital games can make science intrinsically enjoyable is of particular relevance to the policies and activities of governments, scientists and game designers, and it is via these groups, therefore, that this knowledge can most directly strengthen the popularity of scientific culture.

Governments (and to a lesser extent private organisations) frequently wish to raise public awareness regarding some scientific topic. This might be because they desire a new technology to be accepted (e.g. genetically modified foods), because they wish to improve public safety (e.g. respecting high mercury levels in fish), or perhaps because general public cooperation is required (e.g. respecting water and electricity conservation). Now, when the science to be communicated concerns some discrete and specific matter of fact (e.g. certain species of fish should not be consumed by pregnant women because they contain high mercury levels) then the conventional mass media (i.e. newspapers, television, radio) are the media of choice for raising public awareness since these media are better suited than games to conveying factual information. If, however, the science to be communicated relates to the nature of some system and/or how it functions (e.g. the process via which mercury bioaccumulates within marine environments) then digital games are the medium of choice because games are better able to facilitate the construction of experiential and qualitative knowledge than are the other mass media.

Not only do governments frequently wish to raise public awareness regarding particular scientific topics, they also wish to raise public awareness of science in general. As was discussed in Chapter Two, there are economic, utilitarian, democratic, cultural, and social benefits accruing from improvements to public awareness of science, and it is the province of governments to facilitate such improvements. Now, in this context games unequivocally represent the ideal science communication medium both because the qualitative knowledge constructed when playing games acts as a foundation upon which abstract-conceptual knowledge may later be constructed, and also because qualitative understandings are frequently all that people require in order to make useful decisions.

The knowledge that digital games can make science intrinsically enjoyable is of significance for *scientists* primarily because it challenges a core assumption that historically has demotivated science communication efforts: the assumption that science cannot be popularly communicated without being trivialised, sensationalised, or distorted.  Prior to the advent of the digital game there really was no media capable of popularly communicating what is essential to science, and either 'human-interest' (at best) or sensationalism (at worst) was required to make science interesting or enjoyable for laypeople.  With the advent of the digital game, however, a medium now exists that is ideally suited to communicating science, a medium whose very nature is in fact scientific since digital games are based upon simulations and simulations are an increasingly important scientific tool.

Most games created up to this point in time have not been based upon simulations of unfamiliar scientific systems and thus it might seem questionable that the connection between games and science is as strong as is being suggested here.  The digital game is, however, still in its infancy as a communication medium and thus its fundamental nature has yet to be properly appreciated.  When cinema was young, filmmakers filmed the theatre because they were still thinking within the limitations of this medium.  Similarly, early photographers thought of themselves as portrait painters, web-page designers are still struggling to understand that they are not printing onto paper, and game designers still concentrate on simulating sports and borrowing from action movies. The realisation that a whole universe of systems are available for use as the basis of games thus has yet to fully emerge, but given time it will.

Freed from the constraints of human interest and sensationalism, scientists now have the option to publicly communicate their work just as artists (of all varieties) have done for so long. A major difference between art and science, up to now, has been that the products of artists were useable by everyone (at least in theory) while the products of scientists were not. While even small children can gain *some* appreciation from a novel form of visual, auditory, tactile, or gustatory self-expression, only the experts in a given field of science can gain much from reading a journal article, and even they do not usually expect to gain enjoyment. With the development of the digital game, however, the situation has changed and it has now become possible for scientists to publicly exhibit their work in a form that the public can appreciate.

Of course, most scientists will probably not be interested in creating SciSim games based upon their research, yet for a number of reasons it seems inevitable that increasingly scientists will pursue game design and that game designers will base their games upon scientific systems. Among these reasons are that, first of all, simulation use by scientists for purposes of research is increasing and as it does, simulations (and thus also SciSim games) will come to be seen as a natural medium for scientific expression. Second, while many scientists (and particularly the senior ones) working today did not play digital games as children, as time passes this will cease to be true and as scientists' familiarity with games increases so too will their enthusiasm for creating them. Third, game developers are constantly seeking increased realism for their games and this means that they increasingly require direct or indirect collaboration with scientists. Fourth, improvements to computer technology and scientific knowledge constantly make it possible for new areas of science to utilise simulations and consequently for new groups of scientists to create SciSim games. Fifth, it is increasingly the practice of science educators to create educational applets (i.e. simple *Java*- or *Flash*-based simulations) and to place them on the web, and there is only a short distance from this activity to creating SciSim games and placing *them* on the web. Sixth, the rate of usage of digital games within the general population is increasing and they are becoming more established as a medium of communication. Seventh, it is in the interests of scientists to collaborate with the game-industry, and vice versa. Collaboration with the game industry is in the interest of scientists because they must compete with other groups within the community for both funding and authority, and in order to compete more successfully scientists must communicate and popularise their work. There are of course a variety of media via which scientists can communicate their work, yet as this thesis has shown, games are the best medium for the task. Collaboration with scientists is in the interest of the game industry, similarly, because this industry will not grow unless new genres of games are created that will in turn attract new groups of users, and science is a potential source of many new game genres.

It is not being proposed here that scientific culture will become part of popular culture solely because of the incorporation of science within games, but only that SciSim games can increase the popularity of scientific culture. As people gain experience with particular scientific systems through playing games based upon them they will be increasingly able and interested to find out more about these systems via other media. In a world where many people have played 'the benzene-ring game', discussions about benzene rings will have a clarity and purpose that are completely lacking today. The prevalence of SciSim games will act to broaden and deepen peoples' experiences and these new experiences may then be referred to in newspaper articles, books, films and television shows. To say that the existence of a popular scientific culture depends upon SciSim games, then, is only to say that such games are a precondition for it, not that they will constitute its entirety.

How soon scientific culture will become as popular as that of the arts and humanities remains to be seen, yet as is the case with all social issues, one's beliefs about what is possible or desirable in this regard are determinative of what actually takes place. If one says that science cannot be popular, that only 'smart people' can appreciate science, or that science is none of the public's business, then one acts to make these things true. If, by contrast, one believes that a popular scientific culture is inescapable and inevitable then one acts to make this true instead. Of course, the arguments presented in this thesis do not come close to *necessitating* the belief that a popular scientific culture is inevitable, nor even to necessitating the belief that games can make science intrinsically enjoyable. Rather, all these arguments do is provide a strong *theoretical* support for the idea that games can make science intrinsically enjoyable, and it still remains for this idea to be demonstrated in practice on a large scale.

## 3. How To, and How Not To, Design a SciSim Game

Throughout the preceeding chapters, a variety of ideas relevant to the design of science-simulation games have been discussed, and it will be the task of this last section to use these ideas to provide practical guidance to the would-be SciSim game designer. SciSim games are, as we have seen, process-intensive digital games based upon simulations of unfamiliar scientific systems, and during their creation realism is sacrificed for the sake of entertainment. Now, if SciSim games were not based upon unfamiliar scientific systems then they would not be *science* simulation-games, but would simply be digital games. If SciSim games were not process-intensive they would not be science simulation *games*, but would instead be science puzzles. If realism was not sacrificed for entertainment during the creation of SciSim games then they would educational, not communicational games.

### A Game with no Science

From one point of view it would be legitimate to suggest that most digital games are SciSim games because most digital games incorporate some more-or-less complex physical model. When simulated soccer players kick a ball, when simulated racing cars manoeuvre around a racetrack, when simulated soldiers fire their simulated rifles, in all of these instances physical theories initially developed by scientists are being put into practical use, and does this not mean therefore that most digital games are SciSim games? As has already been established, however, digital games facilitate the construction of experiential and qualitative knowledge, and if the player of a game already possesses the experiential and qualitative information communicated by a game then the game cannot really be said to have communicated anything. Since sporting games, driving games and fighting games – indeed, any game based upon a simulation of some familiar terrestrial reality – are not able to provide players with *unfamiliar* physical experiences, therefore, it cannot meaningfully be said of them that they communicate science. Only those games that can assist players to construct new experiential and qualitative knowledge are thus usefully to be classified as SciSim games.

## A Puzzle, not a Game

Digital games communicate "surreptitiously and stealthily", not directly (Prensky, 2001), and thus it is possible for the players of SciSim games to not even be aware that they are constructing scientific knowledge. This is in fact one of the positive attributes of SciSim games – because many people think science is boring and because many game players have negative feelings regarding educational games – yet it is an attribute that is somewhat counterintuitive and difficult to understand. The idea that science can be communicated in the absence of scientific jargon, scientific equipment and mathematical formulae will strike some people as ludicrous, and should such people undertake the task of designing a SciSim game they will most likely end up creating a puzzle-based game instead. As a demonstration of what such a game might look like, and the disadvantages to this approach, the chemistry puzzle-game *Chemicus* (published by *Tivola*) is analysed below. This puzzle-game received much acclamation[♣], it won the *Game Industry News* "Family Entertainment Game of the Year" award for 2003, and as far as data-intensive interactive entertainment is concerned it appears to be of high quality. Because it is data-intensive, however, it is not a SciSim game and is unable to facilitate knowledge construction in the ways that scientific simulations can. Some indication of the nature of *Chemicus* is provided by the following two quotes:

> It's no big secret that I like puzzle games. I love to spend my computer game time solving riddles, fixing machinery, and finding solutions. And if I can learn a thing or two while I'm at it, so much the better. Chemicus was right up my alley. . . . Chemicus is a puzzle game, but you get to (some would probably say "have to") learn so much about chemistry and related fields that I was seriously tempted to declare this a cleverly disguised educational game instead of a puzzle game. (Crowe, 2003)
>
> I didn't expect to like Chemicus. I'd seen it in stores and decided not to buy it. It's edutainment, the scariest word of all our childhoods. It's about chemistry! I like chemistry, but I don't need to recap high school. I did fine the first time. . . . Actually, it's pretty good. Hm. I should say: it's pretty well done. This is not exactly the same thing. What do you expect out of an adventure game based on teaching basic chemistry? You expect a bunch of unrelated chemical experiment puzzles, that's what. (Plotkin, 2003)

The above reviewers agree in at least three different respects regarding *Chemicus*. First, they agree that *Chemicus* is at least in some sense 'good': they did enjoy using it on some level. Second, they agree that *Chemicus* is a puzzle-game. Third, they agree that *Chemicus* is edutainment, or is at least like an educational game. If Chemicus is 'good' and is also puzzle-based and edutainment, though, does this not contradict the general impression given in Chapters Three and Six that puzzle-based interactive entertainments and edutainments are inferior to process-intensive games? In a long review of *Chemicus*

[♣] See http://www.viva-media.com/content.aspx?PageID=1343 (much of which is reprinted below) Plotkin (2003) reveals both that *Chemicus* is a well constructed and enjoyable puzzle-based entertainment *and* that in important respects it fails from a scientific point-of-view. His review thus serves only to reinforce what has been said above.

> What do you expect out of an adventure game based on teaching basic chemistry? You expect a bunch of unrelated chemical experiment puzzles, that's what. Well, Chemicus manages to put together a world of related chemical experiment puzzles. And I don't just mean related in the sense of "produce chemical A, use it as a reagent in experiment B." The designers have a nifty sense of the properties of things – straightforward properties like color and hardness and smell, as well as "scientific" aspects like solubility and electronegativity. All these aspects come into play, in the game's various interactions. It's not like a lab project, "make copper(I) ions". You need the stuff for a specific purpose. Some of the purposes are as reagents in later puzzles; others are required by more fantastic (ie, less realistic) machines. The designers are willing to go either route – whatever it takes to build an interesting scene, or interaction, or puzzle. Really, it's exactly like the design of any other complex adventure game. In a lot of games, the designers think up a bunch of magical (or technological!) spells; they think of cool ways those spells/gadgets could apply to various situations; they invent puzzles; they connect them into a plot. . .
>
> Chemicus is built the same way, except that the "spells" are chemical interactions. And that doesn't indicate a lack of imagination! Most game designers, let's face it, can't invent a system with a tenth of the richness of real-life chemistry. Chemicus has lots and lots to do. It shows off an impressive range of stuff, from acid-base indicators (at the beginning of the game) to organic demos, inorganic demos, chem-engineering tasks, and (at the end) complex molecular analysis. It manages to keep the difficulty pretty even, too. (You get a lot of help on that molecular-analysis bit. You do just enough of the work yourself to get the idea of the whole process.) This approach has down sides as well as up. Many puzzles – interactions – are tied to specific locations, or tools, or actions. That's how the plot is kept in order and the events in their intended context.
>
> This sort of limitation is no problem in a fantasy plot (why shouldn't a ritual be restricted to a given room?) but it hits realism problems in a chemistry game. I counted five – no, seven! – different places in the game where you can heat up a mixture of substances. And each

> one of them is for one particular mixture – perhaps two. Try to cook the right substance in the wrong place, or the wrong substance in the right place, and it just doesn't work. The hotspots won't hot up, as it were; you can't even put the stuff into the bowl (or wherever). Okay, some of these sources are at different temperatures. You can't do organic-solvent distillation in molten lava. Fine! But the game provides no feedback. Nothing indicates that, yes, you can probably melt that somewhere else. I spent quite a lot of time tediously dragging everything I owned onto a particular container, just to see whether this was the right spot for that reaction.
>
> This is the point where the portrayal of a rich, interactive world breaks down into mechanical menu-mashing. It's the usual commercial-adventure lack of flexibility, I know. In an ideal game, you could throw sugar into the bunsen burner, and alcohol into the electrolysis cell, and thermite into the reflux distiller. And the game would show you appropriately disastrous animations, and then your equipment would be ruined. Graphical adventures can't afford all the animations, and their policy is to not let you ruin the equipment. We expect that. But Chemicus really is unnecessarily parsimonious, sometimes. To alloy two metals, you have to: put one metal over heat, melt it, turn the heat off, put the other metal on top of the congealed lump, turn the heat on, turn it off again, take the alloyed lump out, carry it to a different heat source, and melt it again for its final use. What the hell? I think the second source isn't as intense, but it should still be sufficient to melt one metal and then dissolve the other in it! Even if not, the whole sequence is three or four steps too baroque.
>
> I got through that bit because I've played a lot of poorly-designed adventure games. A high-school kid, a non-gamer, who is handed this thing because it's educational – I fear he'd get stuck and frustrated and throw it across the room. (And I won't even get into the electrical contacts that you're supposed to bridge with a conductive substance... a particular conductive substance, out of the five or six I was carrying at the time. Heck, I could have tied a metal wire across the contacts to short them. Would the game let me?) (No, no, never mind that.) (Plotkin, 2003)

Because *Chemicus* is not based upon a simulation it does not actually allow the user to engage in chemistry. It is not, in a sense, *smart enough* to enable chemical reactions to take place amongst the various items that the player is carrying around and thus the player never gets to practice science when playing *Chemicus*, but only to engage in semi-scientific guessing games. Moreover, if they guess wrong, nothing happens at all, whereas in real life all kinds of weird and wonderful – and *new* – things can happen when a variety of substances are heated together. Now, it is true that it is not currently possible to create a simulation-based game which allows the player to do all the things that they can do in *Chemicus*: it probably will not be possible even 100 years from now, given the enormous complexity of the systems involved. It is also true that the player of *Chemicus* will learn a great many chemical facts and will also (superficially) learn the meanings of a great many chemistry-related terms. What the player of *Chemicus* will not do, however, is actually engage in science, and they will not construct either experiential or qualitative knowledge pertaining to chemical systems. *Chemicus* is very high quality edutainment, to be sure, but it is not a SciSim game and possesses none of the advantages of SciSim games as discussed throughout this thesis.

## Educational, not Communicational Games

An easy mistake to make when attempting to design a SciSim game would be to inadvertently design an educational game instead. SciSim games and (process-intensive) educational games are at their cores identical: they are both complex-system simulation-based digital games and thus when designing either sort of game one must find some way of either transforming a complex-system simulation into a game, or else of incorporating a complex-system-simulation within a game. Subsequent to having solved this problem, however, the design challenges presented by these two species of game differ markedly. As was discussed in Chapter Two, the users of educational media do so at the behest of another (a parent or educator), the central challenge of the educational game designer is to create a game that parents and educators believe will be educational, and this ultimately means sacrificing entertainment if it comes into conflict with realism. By contrast, the users of communicational (i.e. entertainment) media decide for themselves what they will use and how they will use it, the central challenge of the communicational game designer is to create a game that people will *want* to play, and this ultimately means sacrificing realism if it comes into conflict with entertainment.

Now, communicational game designers actually do have plenty of reasons for incorporating realism into their games. As we have seen, people enjoy using their existing knowledge in the context of a game, they enjoy the feeling that they are learning something of potential real world value when they play a game, and the complexity of real-world systems can provide a deep and enjoyable challenge for players. Both complexity and realism must, however, be handled carefully if they are to provide the bases for a fun game. It is vitally important, for example, that a gameworld behave in a consistent and logical manner and if ensuring this means cutting down on realism then this is a tradeoff worth making. Similarly, if making a game simple enough to play quickly means reducing the complexity of its underlying simulation then so be it. The games *SimEarth* and *SimLife*, discussed in Chapter Three, were far too realistic and as a result possessed overly steep learning curves and were not enjoyable to play. The automatic policy of trading off realism for entertainment may be seen by some as problematic because of the danger of miseducation, however, in actual fact it is those games that strive most vigorously to be educational that are most likely to miseducate, as the example of *Chemicus* demonstrates. By employing scientific terminology and depicting scientific devices *Chemicus* implicitly makes claims to realism, yet the mechanisms underlying the game are not simulations and in fact have no realism at all. *Chemicus* is thus much like a chemistry student who has been taught exclusively from textbooks: it knows lots of words but has no idea what those words actually refer to. Place this game in charge of educating someone, therefore, and you have the blind leading the blind.

The danger of miseducation through sacrifice of realism is much less severe for players of SciSim games than for players of data-intensive educational games, and for two separate reasons. The first is that SciSim games need (and indeed, should) make no claims regarding realism: the marketing for a SciSim game should not promote the fact that “this game is based upon a scientific simulation”. Such marketing would be entirely appropriate for an educational game, but that is not what a SciSim game is. A SciSim game must be designed and marketed to appeal to those people who will actually be playing the game and claims to scientific realism, while appealing to some potential players, are likely to be unappealing to many more. Of course, the scientific basis for a SciSim game should not be a carefully guarded secret either: it should simply not be promoted. Once someone has begun to play a SciSim game and found it to be enjoyable they will not mind that it is scientifically based. They may even be glad to discover this fact. Before beginning to play a SciSim game, however, a person who hears that it is scientifically based is likely to assume that it is an educational game and this will tend to make it unappealing. Returning to the original point, the danger of miseducation through sacrifice of realism is less of a problem for SciSim games than for educational games because if the players of a SciSim game do not relate to it as representing reality then they cannot be miseducated by any of its deviations from realism.

Even if players do relate to the SciSim game they are playing as realistic, however, there is a second reason why miseducation is less likely to occur with SciSim games than with data-intensive educational games, and this reason relates to the kinds of information (i.e. experiential and qualitative versus abstract-conceptual information) that the two kinds of games communicate. Now, it is relatively easy to miseducate when one communicates facts and abstract-conceptual information. The ratio of a circle's circumference to its diameter, for example, is 3.14159265359 . . , and anything that is not simply a rounded version of this quantity is factually incorrect. Similarly, the relationship between voltage, current and resistance in an electric circuit is V=IR and not I=VR or R=VI, or any other relationship, and if one communicates any other relationship then one has miseducated. When one communicates experiential or qualitative information, however, is much more difficult to be straightforwardly correct or incorrect. Supposing that one created a game based upon the simulation of an atom, for example, in what way could one represent that atom so as to be factually correct? After all, atoms don't *really* look like anything, nor do they *really* feel like anything. This is not an issue that affects only the atomic and sub-atomic realms: in fact it affects all realms that human beings are not usually able to see (or otherwise experience). Consider, for example, the planet Mars. Mars is further from the sun than Earth is so the light that reaches it is weaker, and since its atmosphere is thin the wavelengths of light that reach its surface are different from those that reach the surface of Earth. As a result of these differences, things look different on the surface of Mars than they would on the surface of Earth, yet since our eyes are used to the appearance of things as seen on Earth, what would constitute an 'accurate' image (in terms of colour) of the surface of Mars? Also, the human eye cannot see infrared nor ultraviolet wavelengths, yet these wavelengths can carry much useful information regarding the structure of the surface of Mars, so is it more 'realistic' to communicate this information or not?

Without delving too far into philosophy or psychology this problem can perhaps best be summarized by saying that sense-based experiences are more subjective than is abstract-conceptual knowledge, and thus when one is designing SciSim games (which communicate experiences) it is more difficult to straightforwardly deviate from realism (and to miseducate) than when designing comparable data-intensive educational games. This is not, of course, to say that 'anything goes' when it comes to designing SciSim games, but only that SciSim game designers have more latitude regarding how they choose to express reality than do data-intensive educational game designers.

So far we have seen how *not* to design a SciSim game and how some other forms of game might be created instead. The question still remains to be answered, however, as to how one might actually go about using a scientific system as the basis for a game. How, that is, does one: choose what system to base the game upon; decide what aspect of this system to focus the game on; involve the player in meaningful interaction with this system; provide the player with goals to accomplish; and how does one decide who to design the game for?

## Choosing a Scientific System Upon Which to Base a Game

Treating theoretically the matter of how to choose a scientific system upon which to base a SciSim game, it is reasonable to propose that any and all systems that scientists study can provide the bases for enjoyable digital games. This is in no ways different to proposing that any and all visual scenes can provide the bases for absorbing paintings, or that any and all human situations can provide the bases for interesting narratives. It is the role of artists to see beauty and interest in the mundane and this is true no matter what medium they use to express themselves. Treating the matter more practically, the choice of what system to base a game upon will usually be constrained and informed by the interests and expertise of the game designer and/or of those that fund the game project. So for example, Will Wright designed *SimEarth* because he was interested in the *Gaia hypothesis* and in how counterintuitive the functioning of environmental systems can be (Wright, 2000).

A game designer's choice of systems is not *strictly* limited by their previous interests and expertise because there are many books, journal articles, web sites and software artefacts available to help the would-be SciSim game designer quickly acquire new skills and knowledge. Were one to suddenly become interested in creating a molecular dynamics simulation-based game, for example, then one could purchase *The Art of Molecular Dynamics Simulation* by D.C. Rapaport (1995, Cambridge: Cambridge University Press). Not only does this book explain the process of molecular dynamics simulation, in addition:

> More than 7000 lines of C code are included in the package that can be selectively compiled to produce a total of 43 different programs corresponding to the case studies described in the book. With only a little effort, a wide range of other MD simulations can be constructed from this material . . .♣

Apart from such books there are a great many physics and chemistry applets present on the web that can provide inspiration (not to mention example code) for a SciSim game. Certainly, most of these applets deal with very simple systems, yet as the example of *Sodaplay* (Chapter Three) demonstrates, by coupling a few simple systems together one can create a new system that exhibits very complex behaviours.

## Focus

When designing a SciSim game it is not enough to simply isolate a particular scientific system to act as its basis. This is the beginning, but then one must decide how to focus upon that system. For example, supposing that the phenomena of *surface tension*♣ has been chosen to be the basis for a SciSim game, will surface tension be related to at the level of: the individual molecule; a small group of molecules; or at the level of a great many molecules? Similarly, supposing that a neural system has been chosen to be the basis of a SciSim game, will this game focus upon the level of the synapse, the individual neuron, or the neural network? Focus is important because different games will result depending upon what is focused upon, and some of these games will be more enjoyable to play than others. It may be, for example, that a game designer can think of a great synapse game, but cannot think of an interesting neural network game. That it is possible to focus upon any system at all from different perspectives means that there are

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♣ http://uk.cambridge.org/physics/resources/rapaport/intro.htm

♣ i.e. the enhancement of attractive forces between molecules at the surface of a liquid.

multiple ways of designing any SciSim game, and thus that it should always be possible to find a 'fun' approach to a particular system.

Of particular importance when deciding upon the focus of one's game is that it should incorporate manageable complexity. In Chapter Three a variety of problems were observed to occur when complexity grows too extreme. Overly complex games are hard to balance, their difficulty level may not be controlled, they take a long time to learn how to play, and it is difficult to ensure that they provide the player with clear goals. The most serious problem with the games *SimEarth* and *SimLife* was that they were too complex and thus *out-of-focus*. Ideally, the focus of a SciSim game will be on some phenomenon or system whose behaviour is capable of incremental increases in complexity up to some point where complexity becomes unmanageable for even the expert player. A straightforward means of increasing complexity is model progression (as per Chapter Four), and one type of model progression is the addition of variables. So for example, in the case of a surface-tension game, at the beginning the temperature of the modelled liquid might be constant whereas later on it could begin to vary.

## Involving the Player

Having decided upon the focus of a game, the next problem for the SciSim game designer to be solve is how to involve the player in meaningful and interesting interaction with the focused-upon system. Solving this problem involves determining both how the player will perceive the gameworld and how they will be able to act upon it. With respect to perception, will the player look down on the gameworld from above or will they perceive themselves to be located within it? Will the gameworld be represented in two or three dimensions? With respect to the player's action, will the player control one thing only, a sequence of things, or groups of things? In the case of a SciSim game relating to surface tension, for example, the player might control; a small insect, skating across the surface; some mechanism for selectively disrupting surface tension (in the manner of, but certainly not specifically, a drop of detergent); some mechanism for making waves; the wind, blowing small objects sitting on the liquid; or liquids of different densities that the player could add to the original liquid.

The process of representing the gameworld to players and of allowing them to manipulate it will frequently involve the sacrifice of reality, the inclusion of fantasy elements, and the inclusion of familiar elements. This is because most of the systems that scientists deal with cannot be directly interacted with by human beings, because it is important that the game be aesthetically pleasing and emotionally involving for players, and because too much novelty will scare players away whereas the inclusion of familiar elements will both attract players and make it easier for them to learn how to play the game. The importance of familiar and fantasy elements to a SciSim game may be demonstrated by considering the example of the surface-tension game. Since human beings cannot directly interact with individual water molecules if such interactions are to occur in a game then some familiar and/or fantastic mechanism will need to be invoked to allow them: perhaps the player might control a small spacecraft that can shoot the molecules, or an insect that can bounce upon them. Similarly, in order to make the water molecules aesthetically pleasing they might be given faces, a variety of colours or textures, or the ability to emit sounds.

## Goals

Just as fantasy and familiarity are important components of player interactions with the gameworld, so also they are important components of player goals. A goal, as noted in Chapter Three, is a state of the gameworld that when reached signals an end to the game (or to some section of the game). In most games that deal with mundane activities the goals are quite obvious: win the race, don't crash your vehicle, kick a goal, destroy the enemy. When it comes to unfamiliar systems, by contrast, there are frequently no obvious goals and no states of the system that seem natural as endpoints. Not only will such endpoints need to be artificially added, therefore, but these endpoints must also be chosen so as to be immediately familiar and appealing. If players begin playing one's SciSim game already with some idea of what they are trying to accomplish and how they might go about accomplishing it then they will survive the unfamiliarity of its gameplay much better than if everything is new.

Biological-system based SciSim games are the easiest to find goals for because, at most levels of their organisation, biological systems are 'attempting' to accomplish some goal anyway. A vascular system, for example, is attempting to transport oxygen, nutrients, and waste products; a cell nucleus is attempting to regulate the production of proteins in order to maintain cell integrity; the canopy of a tree is attempting to carry out the functions of respiration and photosynthesis. Physical and chemical systems are not so easily thought of as attempting to accomplish goals, by contrast, and thus in order to create SciSim games based upon such systems the game designer might find it useful to incorporate goals taken from other, more familiar game genres. The *race* is a component of many familiar games and the process of racing could be engaged in by a variety of objects within a variety of physical systems: buoyant objects within convection currents, massive objects within gravitational fields, electrons within electrical conductors, photons within transparent media, and charged objects within electromagnetic fields (cf. *Supercharged* in Chapter Six). Another game genre that is well suited to providing goals for physics- and chemistry-based games is the puzzle genre. Here I am not thinking of data-intensive style puzzles whose challenge is often linguistic or conceptual, but rather puzzles in the style of the *Rubik's Cube* or *Tetris* that are physical and dynamic in nature. Puzzles of this sort could form the basis of SciSim games whose goals were "to create the largest atom possible via the addition of protons, neutrons and electrons" or "to form the largest possible solar system via the accretion of stellar material".

## Users

While digital games are played by people of all ages and both sexes, predominantly players are young and male, and young male players particularly desire high quality graphics and sound, particularly enjoy fighting, sporting, and racing games, and are more willing than other gamers to struggle with complex controls. The games marketplace is crammed full of expensively produced games appealing to this group of gamers and only other expensively produced games have a chance of successfully competing against them. SciSim game designers should thus design for casual gamers who do not demand high quality graphics and sound and who are not bound to a particular genre. Designing for casual gamers is easier, cheaper and faster than designing for young males, and in addition, following this strategy one is also more likely to create a popular game.

The issue of whom SciSim games should be designed for is in one sense a moot one, though, and this is because in the first instance game-designers must always design for themselves. Any creator must necessarily appreciate their own work and have some personal ideal towards which they are striving – otherwise how else will they motivate themselves and make design decisions(?) – and thus they cannot really design for others who have quite different needs and desires. By default, therefore, when one designs a game one is designing for others like oneself: when men design games they are in-part designing for other men, when women design games they are in-part designing for other women, when young people design games they are in-part designing for other young people, and so on. A person’s needs and desires are not determined purely and simply (or even most importantly) by their gender or age, however, and there are numerous personal and idiosyncratic factors that determine one’s needs and desires. It is thus unlikely that some well-defined social group exists to whom one’s game will particularly appeal, and instead potential users will be scattered throughout the world and throughout society. Perhaps the best policy for the SciSim game designer to follow is thus simply to express the beauty, wonder and excitement of the natural world in whatever way possible, and having done so to leave it up to others to decide whether they want to play the game, and what they hope to get out of it.

# Appendix

About.com Computer Simulation Games
Retrieved March 14, 2004, from
compsimgames.about.com/library/blatoz.htm?PM=ss13_compsimgames

Genre Categories:

| | | | | | |
|---|---|---|---|---|---|
| Builder/Manager: | ß, | Flight: | ∞, | Historical: | ∫ |
| Sci/Fantasy: | Ø, | Sport: | Ω, | Car Racing: | Δ |
| Military: | π, | Science: | ∑, | Misc: | ¥ |

**0-9, A**

747 Professional ∞
1503 A.D. ∫
1602 A.D. ∫
911 Paramedic ∑
Aces High ∞
Afterlife Ø
Age of Empires ∫
Age of Mythology ∫
Age of Sail II ∫
Airline ß
Airlines 2 ß
Airport Tycoon ß
Airport Tycoon 2 ß
Alpha Centauri Ø
Alien Nations Ø
Ant War ∑
Apache Havoc ∞
ATC Simulator ∞
Austerlitz ∫
Australian Cricket Captain ß

**B**

B-17 Flying Fortress ∞
Baseball Mogul Ω
Battlefield 1942 ∫
Battle of Britain ∞
Big Biz Tycoon ß

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Postscript

Two books have come to my attention that were published prior to the date of my thesis submission and which are of direct relevance to my topic.  These books are:

Gee, J.P. (2003).  *What video games have to teach us about learning and literacy*. New York: Palgrave MacMillan.

Alessi, S., & Trollip, S. (2001). *Multimedia for learning: Methods and development (3rd ed.)*. New York: Allyn & Bacon.