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Deriving Operational Principles for the Design of Engaging Learning Experiences

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DERIVING OPERATIONAL PRINCIPLES FOR THE DESIGN OF ENGAGING LEARNING EXPERIENCES

by

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GRADUATE COMMITTEE APPROVAL

of a dissertation submitted by

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This dissertation has been read by each member of the following graduate committee and by majority vote has been found to be satisfactory.

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As chair of the candidate's graduate committee, I have read the dissertation of Richard H. Swan in its final form and have found that (1) its format, citations, and bibliographical style are consistent and acceptable and fulfill university and department style requirements; (2) its illustrative materials including figures, tables, and charts are in place; and (3) the final manuscript is satisfactory to the graduate committee and is ready for submission to the university library.

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ABSTRACT

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The issue of learner engagement is an important question for education and for instructional design. It is acknowledged that computer games in general are engaging. Thus, one possible solution to learner engagement is to integrate computer games into education; however, the literature indicates that pedagogical, logistical and political barriers remain. Another possible solution is to derive principles for the design of engaging experiences from a critical examination of computer game design. One possible application of the derived design principles is that instruction may be designed to be inherently more engaging.

The purpose of this dissertation was to look for operational principles underlying the design of computer games in order to better understand the design of engaging experiences. Core design components and associated operational principles for the design of engaging experiences were identified. Selected computer games were analyzed to

demonstrate that these components and principles were present in the design of successful computer games. Selected instructional units were analyzed to show evidence that these operational principles could be applied to the design of instruction. An instructional design theory—called Challenge-driven Instructional Design—and design considerations for the theory were proposed. Finally, suggestions were made for continued development and research of the instructional design theory.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1 — THE ISSUE OF ENGAGEMENT

The purpose of this dissertation is to examine the issue of engagement in education. Whether you use the term *motivation* or *engagement*[1], getting students to be voluntarily involved in the learning process is seen as a necessary condition for real learning to occur (see Blumenfeld, Kempler, & Krajcik, 2006; Buchanan, 2006; Hazemi & Hailes, 2002; Katzeff, 2000). Yet a perennial problem of education is getting students to enjoy and to engage in the learning process (Buchanan, 2006; Csikszentmihalyi, 2002; Gardner, 2002; Krajcik & Blumenfeld, 2006).

Computer Games as a Possible Solution for Engagement

The ability of computer games to engage players has drawn the attention of educators and designers who have proposed that computer games may help solve the problem of engagement (Aldrich, 2004; Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Gee, 2003; Papert, 1998; Prensky, 2001; Rieber, 1996; Rosas et al., 2003; Squire,

[1] These terms sometimes appear to be used synonymously. However, the term *engagement* will be preferred in this dissertation. Motivation can be extrinsic or intrinsic and can be superficial. Engagement connotes a deeper level of motivation and more intrinsic motivation. It is also the term more commonly used in reference to computer games.

2005, 2006). One approach would be to incorporate computer games into the educational curriculum. Over the last three decades there has been significant activity and research regarding the integration of computer games in education (DeFreitas, 2007; Kirriemuir & McFarlane, 2004; Van Eck, 2006). Recent reviews of this research conclude that in general, computer games tend to increase engagement and can assist learning, but also indicate that the integration of computer games into education is not seamless, and significant challenges remain (DeFreitas, 2007; Entertainment & Leisure Software Publishers Association (ELSPA), 2006; Johnson, Spector, Huang, & Novak, 2005; Joint Information Systems Committee (JISC), 2007; Kirriemuir & McFarlane, 2004; Sandford, Ulicsak, Facer, & Rudd, 2006).

Games as Exemplars of the Design of Engaging Experiences

This dissertation takes the approach that of inquiring further into the design of games and to learn from game designers and computer games about how to design for engagement. It is possible to view games from the perspective that they are *designed experiences* (Squire, 2006; Swan, 2005), and further, that they are designed for *optimal engagement* (Buchanan, 2006; Csikszentmihalyi, 1975, 1990; Salen & Zimmerman, 2004). Thus, computer games as a whole may be exemplars of a type of *design of engaging experiences*. By examining games from that perspective, it may be possible to derive fundamental design principles of engagement that can be applied or adapted to the practice of instructional design.

The approach of incorporating games into education to increase engagement has an extensive literature, but it is focused primarily on the surface features of games: It has not looked at the underlying principles that make games engaging (Kirriemuir & McFarlane, 2004). Van Eck (2006) argues that research is needed "explaining *why* [games are] engaging and effective" (p. 32, emphasis in original). Katzeff (2000) asks: "The importance of motivation for the ability to learn is well documented. But with a few exceptions, this feature of learning is rarely addressed in the literature. How do we design for motivation, engagement and immersion (p. 5)?" Finally, Kirriemuir and McFarlane (2004) suggest a deeper look into games:

> Rather than aiming for an experience that superficially resembles leisure-based 'fun' activities, or one which attempts to conceal the educational purpose, it might be argued that we should understand the deep structures of the games play experience that contribute to [optimal engagement] and build these into environments designed to support learning. (p. 6)

The purpose of this dissertation is to inquire into those "deep structures" of games in order to derive design principles of engagement and to examine whether these principles can inform the design of engaging instructional experiences.

Definitions

Operational principle. An *operational principle* is a conceptualization of how a device or designed artifact works. (Operational principle will be discussed in more detail in Chapter Two.)

Computer game. For purposes of this dissertation, *computer game* will refer to games played on computing devices such as personal computers, video game consoles (Wii, Playstation, GameCube, etc.), and other such devices. The term *game* will be understood to refer to computer games as defined above.

Game design. Game design will refer to the process of generating ideas, plans, prototypes, etc. for computer games which may included the documented form of the same.

Engagement. Writers about game design often refer to Mihaly Csiksentmihalyi's psychological theory of optimal engagement (Kirriemuir & McFarlane, 2004; Rieber, 1996; Salen & Zimmerman, 2004), which he calls *flow* (Csikszentmihalyi, 1990). According to Rieber (1996),

> Flow theory gets its name from the way [people] have described a peculiar state of extreme happiness and satisfaction. They are so engaged and absorbed by certain activities that they seem to "flow" along with it in a spontaneous and almost automatic manner—being "carried by the flow" of the activity. (p. 48)

Csikszentmihalyi (1990) refers to flow as a "state in which people are so involved in an activity that nothing else seems to matter; the experience is so enjoyable that people will do it even at great cost, for the sheer sake of doing it" (p. 4). For this dissertation, I will accept this definition of engagement with the note that this is said to refer to *optimal* engagement. This implies that there are degrees of engagement. This dissertation does not advocate that optimal engagement is always necessary or desirable.

CHAPTER 2 — NATURE OF THE STUDY

This dissertation is an inquiry into design. The study of design has become its own discipline often called *Design Studies* or *Design Science* (Bayazit, 2004; Eastman, McCracken, & Newstetter, 2001; Stubbs, 2006; Van Aken, 2004). Instructional design falls within the definition of a design discipline (Gibbons, 2000; Kays, 2003; Merrill, 2001; Reigeluth & Frick, 1999; Silber, 2007; Simon, 1996; Stubbs, 2006). In the last two decades, design research has gained acceptance in the fields of instructional design and education (Bannan-Ritland, 2003; Barab & Squire, 2004; Bunderson, 2000; Collins, Joseph, & Bielaczyc, 2004; Reigeluth & Frick, 1999). Reigeluth & Frick (1999) assert, "…to improve educational practice we need more—and better quality—research on design theory" (p. 650).

The study of design is different in its aims, methods and the knowledge produced than the natural sciences (physics, chemistry, geology, biology) (Bannan-Ritland, 2003; Gibbons, 2000; Reigeluth & Frick, 1999; Simon, 1996; Van Aken, 2004; Vincenti, 1990). Design knowledge answers questions about "how to do" rather than "what is" (Reigeluth & Frick, 1999). Design problems are not well-defined, and solutions are contingent upon the affordances and constraints of the situation as well as the agency of the designer (Gibbons, 2000; Inouye, Merrill, & Swan, 2005; Silber, 2007; Simon, 1996; Van Aken, 2004). Thus, solutions are designed for local conditions, and there is no one right solution but many possible satisfactory designs. In addition, design knowledge is testable and verifiable, but contextually, rather than universally as in the natural sciences (Bannan-Ritland, 2003; Collins et al., 2004; Gibbons, 2000; Van Aken, 2004; Wiley, 2000). In other words, a given design may be satisfactory for a specified context or purpose, but may not work well for another context or purpose.

For example, bridges of the same type will share common characteristics, and yet will have some customization for the specific environment and its intended functions (type of traffic, amount of traffic, etc.). Of course, as contextual differences increase, differences in design will tend to increase. Consider the difference in environment and design between a simple beam bridge, ideal for short spans such as the highway overpass, and the suspended-deck suspension bridge, such as the Golden Gate Bridge.

Nonetheless, Van Aken (2004) indicates that general statements can be made about design knowledge for classes of problems, however, these statements are in the form of guiding principles or heuristics rather than laws of nature. These conceptual or theoretical tools comprise essential knowledge that is intrinsic to design (Gibbons, 2000; Merrill, 2001; Simon, 1996; Vincenti, 1990).

Fundamental Design Concepts

Vincenti (1990) describes several classes of design knowledge. Among these is the class he calls *fundamental design concepts*. According to Vincenti, these are concepts that exist in the mind of the designer about how a given device works and how the device is configured. Of particular importance to this dissertation is the concept of *operational principle*.

Operational Principle

The term *operational principle* was first coined by Polanyi (1962). According to Polanyi, an operational principle describes "how [a device's] characteristic parts…fulfill their special function in combining to an overall operation which achieves the purpose" (p. 328). Quoting Vincenti (1990), Gibbons (2000) describes operational principle as "…'the essential characterization of how the device works.' It is a description of the primitive forces acting either in opposition or in harmony to produce the technology's effect" (p. 14). Thus, operational principles may be understood as describing the relationships and interactions between designed structures and their environment.

Operational principles are abstractions that are made concrete through the production of an artifact. According to Vincenti (1990), every device embodies an operational principle. As the design of a device matures, a consensus tends to emerge about the overall shape and arrangement of the device (Murmann & Frenken, 2006). Vincenti (1990) relates that after the Wright Brothers established a successful method of flight, engineers spent years of design experimentation on different configurations of airplane before the arrangement of propeller and fixed single wing front, and tail aft, became the norm.

Normal Configuration

For Vincenti, the informal consensus of arrangement is the other fundamental design concept which he calls the *normal configuration* (Vincenti, 1990). The normal configuration is the designer's preconception of what the physical form of the artifact ought to be like. For example, designing a sedan versus a pickup truck suggests differences in general shape. Gagne's model, the nine events of instruction, suggests a standard structure, and therefore, could be considered an example of a proposed normal configuration from the field of instructional design.

Thus, the normal configuration can be thought of as a *de facto* standard that is generally considered to be well-suited to the purpose (Vincenti, 1990). Of course, the normal configuration is not the only possible configuration. As Rogers, Hsueh, & Gibbons (2005) indicate, "From the operational principle, designers can generate many configurations, of which the 'normal' configuration is just one of many options" (p. 1).

An important point is that operational principle and normal configuration represent *the designer's conceptualization*. They are not physical objects; nor do they necessarily represent established theory. Rather, they are the foundational assumptions of the designer. Vincenti (1990) indicates,

> Designers …bring with them fundamental concepts about the device in question. These concepts [operational principle and normal configuration] may exist only implicitly in the back of the designer's mind, but they must be there. They are the givens for the project, even if unstated. (p. 208)

As assumptions, these concepts establish the boundaries of the design task. As with any assumption, these preconceptions may be flawed. Consequently, the search for a more suitable design may require the designer to reformulate the operational principle and/or configuration (Gibbons, 2000; Murmann & Frenken, 2006; Vincenti, 1990). In the development of the airplane, Vincenti (1990) notes that reconceiving the operational principle as "propelling a rigid surface forward through the resisting air…freed designers from the previous impractical notion of flapping wings" (p. 208). Gibbons indicates,

> operational principles are simply different framings or structurings of force, information, and materials useful for the solution of a technological

> problem. …Operational principles are how we attack a larger problem to break it down into smaller, solvable problems. They often require the re-expression of old problems in new terms that describe new balances of forces. (p. 15)

It is important to note that operational principles need not be understood *explicitly* in order for designers to create functioning devices; they can be applied intuitively or serendipitously (Gibbons, 2000; Vincenti, 1990). It is equally important to note that making operational principles explicit tends to improve the quality of designs, and reveals new avenues of design, development and technological research (Gibbons, 2000; Rogers et al., 2005; Vincenti, 1990). Thus, understanding operational principles, normal configurations, and their relationships gives the designer a conceptual framework with which to generate, adapt and refine possible design solutions for a wide variety of situations.

Contribution to the Field of Instructional Design

This study contributes to design knowledge, and to instructional design in particular, by making explicit operational principles that pertain to the design of engaging experiences—a significant first step toward understanding and improving the design of engaging instruction. Understanding operational principles of engagement would contribute to the field of instructional design in the following ways

1. *Informing the integration of commercial games into instructional settings.* Understanding how and why games work, and understanding that these same principles can apply to the instructional context surrounding the use of the game, will help the instructor/designer understand what the game can and cannot do instructionally, and help them create instruction that transitions into and out of the game more smoothly. Thus, by understanding the operational principles of engagement, educators will be better able to integrate computer games into the curriculum where games are appropriate.
2. *Designing better educational games.* There have been some notable successes in the realm of educational games such as Quest Atlantis (Barab et al., 2005), however, educational games (also referred to as edutainment) have not been successful overall (Fortugno & Zimmerman, 2005; Kirriemuir & McFarlane, 2004). Understanding operational principles of engagement and how they relate to instruction will help educational game designers create educational games that are both instructive and engaging.
3. *Designing more engaging instruction in general.* Computer games are not always available nor are they always appropriate (Van Eck, 2006).

However, the design of engaging experiences should not be limited to computer games and instruction should not be automatically relegated to boredom. Again, understanding the design principles of engagement and how they can be put into practice can improve the engagingness of most instructional situations.

4. *Contributing to design theory.* One of the purposes of design research is to advance the theoretical basis for design (Bannan-Ritland, 2003; Collins et al., 2004; Gibbons, 2000; Reigeluth & Frick, 1999). Defining operational principles of engagement would provide a beginning design hypothesis for continued design experimentation and theoretical development, thus contributing to the body of design knowledge.

Assumptions

Following are the essential assumptions on which this study is founded:

1. Engaging experiences can be designed.
2. Computer games (as a whole) represent an exemplary class of experiences designed for engagement.
3. There are operational principles of engagement that have not been made explicit, but are being applied by game designers intuitively or serendipitously.

4. Instructional experiences can be designed to be *both* instructive and engaging.

Reverse Engineering Questions

The purpose of this dissertation is to derive operational principles of the design of engagement from computer games, and to examine similarities and differences in the application of these principles to instructional design. Thus, the first reverse engineering question is framed as follows:

1. By examining the design of computer games as an exemplar, can I, as the reverse engineer, identify and describe operational principles for the design of engaging experiences?

The second reverse engineering question is formulated as follows:

2. Can evidence be provided that these operational principles apply to the design of engaging instruction?

CHAPTER 3 — METHODOLOGY

Only recently has the field of instructional design begun to systematically compare itself to other design fields such as engineering and architecture (Bannan-Ritland, 2003; Gibbons, 2000; Silber, 2007; Stubbs, 2006; Van den Akker, Gravemeijer, McKenney, & Nieveen, 2006). This comparison to engineering served as a foundation to generate a new research approach in education called *design research* (Bannan-Ritland, 2003, 2008; Barab & Squire, 2004; Collins et al., 2004). Design research is not single methodology, but comprises a variety of methods (Bannan-Ritland, 2003; Barab & Squire, 2004; Van den Akker et al., 2006). According to Bannan-Ritland (2003; 2008), design research is best characterized as a meta-method which incorporates methods from instructional systems design (ISD), learning sciences, and other design fields such as engineering.

Design research is an iterative process (Bannan-Ritland, 2003, 2008; Barab & Squire, 2004; Bunderson, 2000; Nieveen, McKenney, & Van den Akker, 2006) and occurs in stages or phases (Bannan-Ritland, 2003, 2008; Nieveen et al., 2006). Bannan-Ritland (2003; 2008) describes a design research framework that includes four phases: (a) informed exploration, (b) enactment, (c) evaluation: local impact, and (d) evaluation: broader impact. The phase that corresponds to this dissertation is informed exploration.

The body of design research in our field focuses primarily on following a product or intervention through multiple design and implementation cycles (Bannan-Ritland, 2003, 2008; Barab & Squire, 2004; Collins et al., 2004). This dissertation differs in that it looks at a category of designed products from the perspective of operational principles. In my review of the research literature, I found no research precedents from instructional design or educational design research that directly endeavored to identify and describe operational principles. Nonetheless, the goals of this dissertation fit the purposes of design research in general and informed exploration in particular. Collins et al. (2004) assert, "Design research should always have the dual goals of refining both theory and practice" (p. 5). Among the purposes of informed exploration, according to Bannan-Ritland (2008), are (a) to identify, describe, and analyze the state of the problem or phenomenon; (b) to generate perspectives about how people learn and perform; and (c) to determine corresponding design directions. These purposes correspond closely to the intended outcomes of this dissertation.

Although there are no directly related methods, Reigeluth and associates (Reigeluth & Frick, 1999; Reigeluth & Yun-Jo, 2006) put forward a design research method for building design theory called *formative research* which provides an appropriate framework for this study. In addition, Gibbons (2000) provides direction for the specific task of identifying operational principles: "One phase of formal research seeks to understand operating principles and normal configurations that have come into common use through serendipity or common usage by *reverse engineering* them—analyzing their internal and external dynamics" (p. 21, emphasis added). One field in which reverse engineering is a common practice is computer software engineering. Thus, software reverse engineering will supply additional guidelines.

Formative Research

Reigeluth and associates (Reigeluth & Frick, 1999; Reigeluth & Yun-Jo, 2006) argue that quantitative, experimental methods are not well-suited to the production of design knowledge (see also Bannan-Ritland, 2003, 2008; Barab & Squire, 2004; Collins et al., 2004; Gibbons, 2000; Lynham, 2002; Van Aken, 2004). Ethnographic studies also do not directly address many issues relevant to design practice (Collins et al., 2004; Reigeluth & Frick, 1999). Therefore, Reigeluth and Frick (1999) propose a method for generating design theory they call *formative research*.

Formative research was developed in part from an examination of a many studies that developed design theories. Reigeluth and Frick (1999) identify three types of formative research: *designed cases*, *in vivo naturalistic cases*, and *post facto naturalistic cases*. They further distinguish two purposes for each type of study: to improve an existing theory, or to develop a new theory (see Table 1).

Table 1.

*Kinds of formative research studies**

	For an existing theory	For a new theory
Type of case	Designed case	Designed case
	In vivo naturalistic case	*In vivo* naturalistic case
	Post facto naturalistic case	*Post facto* naturalistic case

* adapted from Reigeluth & Frick (1999)

For a designed case, the designer/researcher creates an instantiation of the theory and then conducts research on the case. A naturalistic case selects a case that was not specifically designed as an instance of the theory. The authors indicate that naturalistic case can be researched either while the instance is being applied (*in vivo*) or after the instance has been applied (*post facto*). This dissertation will be researching computer games and computer game design as they exist and after the fact. In addition, making the operational principle explicit is analogous to developing a new theory. Therefore, this study is best characterized as a *post facto* naturalistic case for a new theory.

For this type of study, Reigeluth and Frick (1999) delineate a three step process:

1. Select a case.
2. Collect and analyze formative data on the case.
3. Fully develop your tentative theory.

Most of Reigeluth and Frick's (1999) recommendations for data collection and analysis are made for studies of existing theories rather than new theories. The recommendations for new theories are, however, consistent with the ideas of reverse engineering. Therefore, guidelines for software reverse engineering will provide a basis for the data collection and analysis step of this study.

Software Reverse Engineering

Chu (2002), citing Chikofsky (1990), defines *reverse engineering* as "the process of analyzing a subject system to identify the system's components and their inter-relationships, and to create representations of the system in another form or at a higher level of abstraction" (p. 2). Thus, as Figure 1 illustrates, the process of reverse engineering is moving up from a less abstract level to a higher level of abstraction (Byrne, 1992; Chu et al., 2002; Rosenberg & Hyatt, 1997).

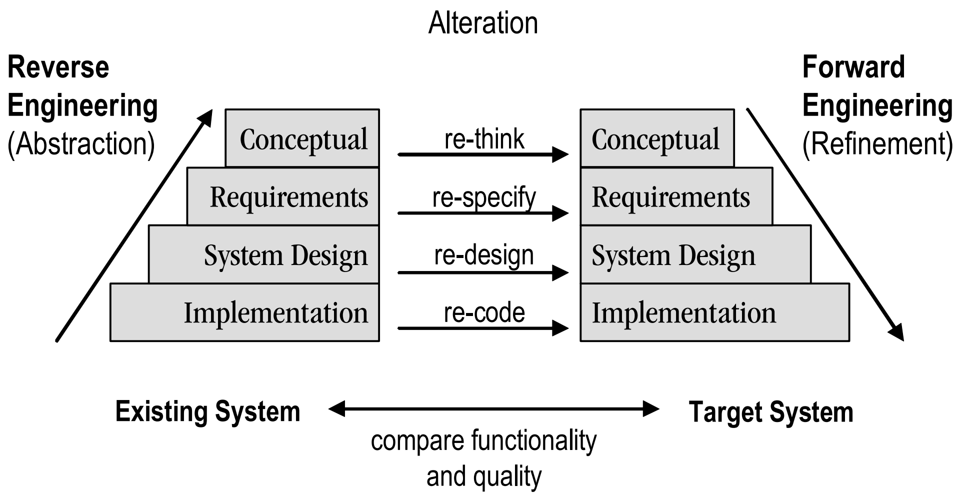

Figure 1. General Model for Software Re-engineering

As seen in Figure 1, software reverse engineering is commonly associated with *re-engineering* due to the need to update older versions of software for newer platforms and programming languages. In this context, reverse engineering is viewed as the first step of re-engineering (Kuhlman, 2004; Rosenberg, 1996; Sora, 2005). The goal of re-engineering is to replicate and/or improve an existing system usually in a more current programming language or more current hardware platform (Byrne, 1992; Chu, Lu, Chang, & Chung, 2001; Gannod & Cheng, 1996; Rosenberg, 1996). Thus, re-engineering consists of reverse engineering followed by *forward engineering* (the normal process of engineering) for the target system (Byrne, 1992; Kuhlman, 2004; Rosenberg, 1996; Rosenberg & Hyatt, 1997).

However, Canfora & DiPenta (2007) note that reverse engineering can and should be an end in itself. One of the purposes of reverse engineering is to find design information that is reusable for more than the design of a single system (Canfora & Di Penta, 2007; Chu et al., 2001; Chu et al., 2002). This purpose is congruent with the goals of this dissertation.

The general first step of reverse engineering is to extract information to better understand the system (Canfora & Di Penta, 2007; Rosenberg, 1996). The general second step is to generate appropriate abstractions from the information gathered (Canfora & Di Penta, 2007). As a final step, Rosenberg (1996) suggests that the recovered design should be "reviewed for consistency and correctness" (p. 6). This can be accomplished by comparing the emerging system model with other sources or artifacts as well as comparing the design information to the existing system (Canfora & Di Penta, 2007; Li, Yang, & Chu, 2002; Suc & Bratko, 2002).

Combined Method

Combining formative research and reverse engineering yields the process which will be followed in this study:

1. Select a case.
2. Collect and analyze formative data on the case.

a. Collect information to understand the existing system.

b. Generate appropriate abstractions (identify and describe operational principle).

c. Compare design information to existing system (Confirm and illustrate operational principle by applying to an appropriate range of configurations).

3. Fully develop your tentative theory.

Select a Case

Reigeluth and Frick (1999) indicate that the selected case should fit within the general class to which the theory applies and "be as close as possible to being an instance of the theory—i.e., it will contain many of the elements that are called for by the theory" (p. 645). Further, Stake (2005) indicates that there are three types of case studies: the *intrinsic case study* which focuses on a single case to understand the case itself without generalizing to other cases; the *instrumental case study* which focuses on a single case as representative of other similar cases; and the *collective case study* which uses multiple cases in order to generalize about a class of cases. This study uses selected computer games as a collective case from which to generalize to the class of designed engaging experiences.

Understand the Existing System

Kuhlman (2004, citing Chikofsky & Cross 1990) indicates that reverse engineering "can start at any level of abstraction as an existing functional system is not a prerequisite" (p. 21). The reverse engineer uses whatever information or artifacts are available to understand the system in question (Canfora & Di Penta, 2007; Chu et al., 2002; Kuhlman, 2004). This includes design documentation, diagrams, the functioning system, the source code, and the expertise and experience of the reverse engineer (Chu et al., 2002; Li et al., 2002; Rosenberg, 1996; Suc & Bratko, 2002).

The goal of this step is to understand the design of computer games in general. Therefore, this study reviews the literature (largely from practicing designers) on game design. The purpose of this review is not to understand how to make a game, but to find the design components that make a game engaging.

Generate the Appropriate Abstraction

Generating the appropriate abstraction depends on the level of abstraction from which you begin and the level of abstraction at which you want to end. At the level of implementation (see Figure 1 above), much of the research surrounds the development of software tools to streamline the time-intensive work of analyzing source code (Jarzabek & Tan Poh, 1995; Keller, Schauer, Robitaille, & Page, 1999; Lanza & Ducasse, 2003; Li et al., 2002). However, reverse engineering, especially at higher levels of abstraction, still relies primarily on human cognition, or the expertise of the reverse engineer, to identify patterns and underlying structures (Chu et al., 2002; Jarzabek & Tan Poh, 1995; Keller et al., 1999; Li et al., 2002). In the case of generating new design theory, Reigeluth and Frick (1999) concur, "You need to rely heavily on your intuition, experience, and knowledge of relevant descriptive theory to develop hypotheses as to what might generalize from this case" (p. 646).

This dissertation is starting at an abstract level by looking at computer games as a class, and abstracting further to the level of operational principle. Thus, the method here relies on my experience and abilities as the reverse engineer. From this synthesis, I will postulate the operational principle(s) on which they rest.

Compare Design to Existing System

As a confirmatory step, Suc & Bratko (2002) indicate that the results of reverse engineering should provide a suitable explanation of the design strategy embodied in a given system. This can be accomplished by comparing the emerging system model with other sources or artifacts as well as comparing the design information to an existing system (Canfora & Di Penta, 2007; Li et al., 2002; Suc & Bratko, 2002). In like manner, an operational principle should apply to a range of possible configurations (Gibbons, 2000; Rogers et al., 2005; Vincenti, 1990). Therefore, this study will substantiate the operational principles by describing their occurrence within existing computer games. This is the concluding step for answering the first reverse engineering question of this dissertation.

The second reverse engineering question is answered by substantiating the presence of these operational principles within instruction. If this study can show that these operational principles are present, even if they are not instantiated well, it provides evidence that these operational principles could be factored into the design of instruction. Consequently, this study will compare the operational principles to instances of designed instruction.

Further, since instruction would represent a different type of configuration, some structural and operational differences would be expected. Thus, this comparison should also help illuminate how instructional engagement might differ from game engagement.

To cover all variations of computer games and instruction would be impractical. However, Stake (1995) notes that time and resources are always limited. He asserts that understanding the selected case(s) is more important than the number of cases. Moreover, this study can cover a reasonable range of differentiating characteristics with a limited set of cases. The selection of computer games and instructional units for comparison is described below.

Formulate a Tentative Theory

The final step is to propose a design theory based on the identified operational principles. Reigeluth & Frick (1999) indicate that findings from the study should be used to outline a tentative theory (a single study being insufficient to validate a theory). Further, the strengths and weaknesses of the theory should be discussed, as well as identifying possible avenues for further research.

This dissertation will conclude with a discussion of a proposed instructional design theory called Challenge-Driven Instructional Design. The structural elements of the theory will be outlined. Implications of the theory for in-classroom implementation will be discussed. Finally, suggestions for possible research will be given.

Selection of Comparison Cases

This study will examine four different computer games in light of the proposed operational principles. The study will also analyze two case of designed instruction to demonstrate the presence of the operational principles.

Computer Games

The selected games are *Delta Force 3* (DF3), *Mario Kart: Double Dash* (*Mario Kart*), *7th Guest*, and *Tetris*. It should be noted that each of these games was popular at the time of its release. Their commercial success is an indicator that at some time they were successful in engaging players. This fits the study's purpose, which is to study engagement. This also follows the recommendation of Reigeluth and Frick (1999) to select cases that are close to the design theory under development. Some distinguishing features of these games are compared in Table 2.

Table 2.

Computer games selected for comparison to operational principles

Game	Game Type	Representation	Narrative	Win Condition	Other
Delta Force 3	Adventure	Realistic	Backstory	Yes	Complex controls
Mario Kart: Double Dash	Racing	Cartoon Fantasy	Implied	Yes	Power-ups
7th Guest	Interactive Story	Realistic Fantasy	Narrative-driven	?	Cut-scenes
Tetris	Puzzle	Abstract	No Story	No	High score

Delta Force 3. DF3 is a realistic, 3-D, combat game from a first-person perspective; you view the game as if you were present in the game-world. DF3 fits into the category of a “first-person shooter.” The backstory of DF3 is that you are a member of the elite military corps known as the Delta Force. (*Backstory* is a term borrowed from film and drama. It refers to the “story” that sets up the dramatized story of the play or film; in other words, it is the background or history that has given rise to the current situation.) You will participate in various covert missions to counteract terrorism and the illicit drug trade. With each mission, you receive a debriefing that specifies the objective and the win condition. When the debriefing is over, the narrative portion ends, and the game begins.

Mario Kart: Double Dash. Mario Kart features the cartoon characters from Nintendo’s “Mario” franchise. *Mario Kart* is a racing game from a 3-D third-person “over-the-shoulder” perspective. From this perspective you are looking “over the shoulder” of your chosen character, or “avatar,” and you are controlling the avatar. To some degree, the game inherits the backstory from other Mario titles; you may recognize the heroes, the sidekicks, and the villains. Otherwise, there is no narrative present and the progression is not tied together by narrative elements. *Mario Kart* also features *power-ups*, or items that give you temporary powers that help you and/or hinder your opponents. Finally *Mario Kart* can be considered a *twitch-speed* game. Twitch-speed refers to the almost instantaneous reaction necessary to maneuver, and avoid or attack opposition in many action games. As a racing game, the win condition is crossing the finish line first.

7th Guest. *7th Guest* is a mystery story that is revealed as you maneuver through a realistic 3-D haunted mansion. The perspective is also first-person. As you navigate the mansion, you encounter puzzles. By solving a puzzle, another piece of the mystery story is revealed through video cut-scenes. A cut-scene stops the gameplay to play a scene that advances the storyline; there is limited or no interactivity during cut-scenes. Thus, it is debatable whether *7th Guest* is, strictly speaking, a game (Crawford, 2003; Rouse, 2001). It might be better termed an "interactive story" (Rouse, 2001). In addition, it has the simplest controls of all the games. Further, while there are win conditions for the individual puzzles, you do not "win" the game. Rather, *7th Guest* reveals the conclusion of the story through a final cut-scene.

Tetris. You are not *in* the world of *Tetris*; rather, you are looking down on a 2-D playing area. *Tetris* uses abstract shapes based on the possible combinations of four attached squares. These shapes randomly drop, one at a time, from the top to the bottom. You can rotate shapes by 90° increments to find the best fit with preceding shapes. When a row is completely full, it disappears, points are won, and any incomplete rows drop down to fill the empty space. There is no win condition in *Tetris*; shapes keep dropping with increasing speed until the entrance for a new shape is blocked. The goal is to survive as long as possible and accrue a greater number of points. There is no narrative element.

It probably best characterized as a puzzle game (Rollings & Adams, 2003; Rouse, 2001). There is also some minor debate as to whether a puzzle is a game (Crawford, 1984; Salen & Zimmerman, 2004); however, for this dissertation I will accept the classification of *Tetris* as a puzzle game (Rollings & Adams, 2003; Rouse, 2001; Salen & Zimmerman, 2004).

Instructional Units

As Reigeluth and Frick (1999) indicate, cases should be as close as possible to the theory. Therefore, the study should include instruction that has been designed, at least in part, to be engaging. For the last decade, I have been developing instructional materials, attempting to emulate games in non-game instruction in order to improve engagement. (It is from these efforts that this study is derived.) Two of these instructional products represent different types of instructional materials, and different levels of conceptual development.

While the selection of these cases may raise concerns about objectivity, several authors indicate that the researcher's expertise and familiarity with the subject could be a benefit since it would allow for more refined insights that might not be possible from an outside observer (Cutcliffe, 2000; Eisner, 1998; Stake, 1995; Stubbs, 2006). This would be particularly true for theory generating studies (Gerring, 2007; Glaser & Strauss, 1967). Glaser and Strauss (1967) state,

> Through his own experiences, general knowledge, or reading, and the stories of others, the [researcher] can gain data…that offer useful comparison. This kind of data can be trusted if it has been 'lived'. Anecdotal comparisons are especially useful in starting research and developing core categories. (p. 67)

Lincoln & Guba (1985) also note "... admitting tacit knowledge not only widens the investigator's ability to apprehend and adjust to phenomenon in context, it also enables the emergence of theory that could not otherwise have been articulated" (p. 208). Therefore, this closeness to the subject enables observations that might otherwise not be available.

From my vantage point as the designer, I can comment not only on the execution and outcomes of the instruction, but also on the design intentions, constraints and considerations. This design perspective is valuable in reverse engineering as well (Chu et al., 2002; Li et al., 2002; Suc & Bratko, 2002) and is not uncommon in design research (Collins et al., 2004; Reigeluth & Frick, 1999). Consequently, I propose to analyze the design of an instructional simulation, Virtual ChemLab: Inorganic Qualitative Analysis (Virtual ChemLab), and a full-length course, Biology 100: General Biology (BIO 100).

As a realistic simulation, Virtual ChemLab would represent instruction that is more game-like. Bio 100 would make an excellent contrasting case since it is a full course and is not intrinsically technology-rich, nor technology-dependent. Furthermore, it includes lecture-based classroom instruction—the least game-like and purportedly the least engaging (Papert, 1998; Prensky, 2001).

Virtual ChemLab. Virtual ChemLab is a computer-based, realistic simulation of a chemistry laboratory. One of the limitations of real laboratories was that step-by-step procedures were required to be given to students to avoid accidents and liability. Consequently, students could follow the instructions very successfully and yet avoid any real understanding of chemistry and the reasoning processes behind chemistry. The purpose for developing this simulation was to provide an environment which would allow real experimentation and promote scientific reasoning. However, the design team recognized that to accomplish this goal, student engagement was a necessary prerequisite. The design team consciously chose to mimic aspects of a then-popular game, *Doom*. This effort represented a more intuitive or serendipitous attempt to adapt game ideas to instruction. The module that this study will examine is Inorganic Qualitative Analysis.

Biology 100. In the summer of 2005, the program coordinator for Bio 100 participated in a program called the Faculty Fellowship (Fellowship) sponsored by the

Center for Instructional Design at BYU. The purpose of the Fellowship was to bring faculty together to discuss both theory and application that would result in a project for course improvement. As a result of the Fellowship, the program coordinator agreed that the course, as a whole, needed to be redesigned to address several issues. The issues identified were

- Students in general demonstrated low engagement; they were taking Bio 100 because it was a General Education requirement.
- Students generally did not perceive the content of Bio 100 as relevant to their lives.
- The coordinator wanted the course to move away from memorization of content and move toward developing intellectual abilities.

Therefore, engagement was one of the primary issues for the redesign of Bio 100.

Virtual ChemLab and Bio 100 were designed, in part, with the goal of improving engagement. If the identified operational principles are applicable to instructional design, the process of reverse engineering in this study should be able to find and describe them in these designed instructional units. These two instructional products, therefore, will help us establish a range of possible application of the design theory.

Criteria for Evaluating the Study

To summarize, the purpose of postulating operational principles is to provide designers with a more explicit conceptual understanding of a given design problem. This dissertation does not claim to advance a proven or provable theory in a scientific sense. Rather, this dissertation claims to advance an explicit conceptual foundation for the design of engaging learning experiences. Therefore, criteria that are appropriate for evaluating this study are *correspondence* from software reverse engineering (Suc & Bratko, 2002), and *transportability* from design research (Middleton, Gorard, Taylor, & Bannan-Ritland, 2006).

Correspondence

Suc & Bratko (2002) suggest a criterion from reverse engineering for evaluating proposed operational principles—that the operational principles should provide a suitable explanation of the design strategy embodied in existing systems; in other words, that there is a *correspondence* between the design description and the functioning system (see also Rosenberg, 1996). Thus, the operational principles in this dissertation should help us explain why and how game design elements work together to achieve engagement.

Transportability

In addition, operational principles should help the designer approach a future design problem with more clarity or new insight. Middleton et al. (2006) refer to this criteria as *transportability*, or "the efficacy a design provides beyond its initial conditions of development" (p. 6). In other words, the design theory should be applicable to other design situations beyond the case under study. For Middleton et al. (2006) *transportability* is the design research analogue to *generalizability* in the natural sciences, and to *transferability* in qualitative or ethnographic research. Therefore, the operational principles enunciated herein should demonstrate applicability to other design situations.

CHAPTER 4 — IDENTIFICATION OF POSSIBLE CORE COMPONENTS OF COMPUTER GAMES

To derive operational principles, I, as the reverse engineer, need to identify the essential structural design elements of the artifact in question. For example, in the operational principle of the airplane, the structural elements identified are the rigid surface (fixed wing) and the means of propelling the wing through air (Vincenti, 1990). Notice that the essential elements of an airplane are a small set of elements in the overall design.

Murmann and Frenken (2006) refer to this subset of structures as *core components*. Elements that are supportive, or are present for other purposes, they call *peripheral components*. A change to the core components changes the nature of the thing. For example, changing the fixed wing to a rotary blade changes the nature of the aircraft. A change to peripheral components may change the physical form and the functional properties of the thing, but does not change its essential nature. A plane with retractable landing gear and one with fixed landing gear are both still airplanes, for example. Thus, the purpose of the review of game design literature is to identify these *core components* that appear to define the essential nature of computer games.

While there is an increasing body of literature about game design, much of it focuses on tactical issues of how to make a computer game: for example, how to design characters, how to use audio, and so forth. When they discuss the general structure of games they often cite a handful of influential practitioners who have written about game design at a more conceptual level. Among these are Chris Crawford, Greg Costikyan, Andrew Rollings and Ernest Adams, and Katie Salen and Eric Zimmerman. These will form the core group of game design authors that will be reviewed.

Analysis of Game Components from Selected Game Designers

The review of key authors will first identify those structural elements that each individual author considers essential. These elements will comprise the list of potential core components. Based on this analysis, I will endeavor to synthesize a set of core components as the structural basis of operational principles of engaging experiences.

Chris Crawford

In 1984, Chris Crawford published *The Art of Computer Game Design*. This work is still referenced today. Crawford followed this with *Chris Crawford on Game Design* in 2003. In these two books, Crawford defines a game alternatively as "a closed formal system that subjectively represents a subset of reality" (Crawford, 1984, Chapter 1) and as "conflicts in which the players directly interact …to foil each other's goals" (Crawford, 2003, p. 8). These two definitions are complementary. The discussion begins with elements from the 1984 definition.

According Crawford (1984), a game has a set of interacting parts, thus, it is a system. Further, it is a closed system: "The model world created by the game is internally complete; no reference need be made to agents outside of the game" (Chapter 1). The system provides the setting for the game. Crawford (2003) asserts that "all challenges take place in some sort of defined context" (p. 37). Since *system* describes the whole and not the constituent components; therefore, it does not fit the criteria as a possible core component of games to be included in the synthesis phase of the study.

Rules. By "formal" Crawford (1984) means "that the game has explicit rules" (Chapter 1). Rules, according to Crawford (2003), are "the conditions under which a challenge is presented" (p. 38). It could be said that, for a game, the rules establish the constraints that make the activity a challenge. Crawford (2003) distinguishes between inherent rules that are beyond the player's control such as the laws of nature, and the administrative rules that more directly determine the form of the game. *Rules* would be a constituent component of games; therefore, I will include it as a possible core component of games to be considered in the synthesis that follows.

Focused fantasy. Also, according to Crawford (1984), a game's context cannot represent all of reality, it can only represent a subset of reality. Crawford (1984) also refers to this as the *central theme*, or *topic*, or "the environment in which the game will be played. It is the concrete collection of conditions and events through which the [game's] goal will be communicated" (Chapter 5). Further, Crawford (1984) indicates that this subset establishes a *focus* to the game which reduces reality to a manageable level for the player. He indicates, "A game that represents too large a subset of reality defies the player's comprehension and becomes almost indistinguishable from life itself, robbing the game of one of its most appealing factors, its focus" (Chapter 1).

Moreover, the reality it represents is not a physical or objective reality; it is a subjective or emotional reality. Crawford (2003) provides this example:

> An accurate simulation of WWII fighter combat would have been dreadfully boring. You'd take off, fly for several hours to the combat zone, hear all sorts of excitement over the radio, fly around looking for enemy aircraft. …Very rarely would you chance upon an encounter with even enough odds to entice both sides to accept battle. …But a game is a different matter; it must model the emotional realities of air combat, and from that point of view, all the missed opportunities and eventless hours

are non-entities. …therefore, a good air combat game will twist reality around to emphasize the emotionally significant parts. (pp. 29-30)

The subjective nature of the subset, Crawford (1984) would characterize as fantasy. He states, "The agent that transforms an objectively unreal situation into a subjectively real one is human fantasy. Fantasy thus plays a vital role in any game situation. A game creates a fantasy representation, not a scientific model" (Chapter 1). Fantasy in this context should not be confused with exotic settings or fairy tales. For Crawford at least, games that are based on reality are still fantasy as the example above illustrates. My reading of Crawford is that by fantasy he means the intersection where altered reality stimulates human imagination. The term that this study will adopt to best capture Crawford's intent is *focused fantasy*. Thus, from Crawford's (1984) definition, I will identify two design elements as potential core components of games: 1) rules and 2) focused fantasy. These elements will be considered in the subsequent synthesis phase.

Inter-player conflict. To understand Crawford's (2003) second definition of a game (conflicts in which the players directly interact to foil each other's goals), one must first understand that for Crawford, conflict is a subtype of challenge and game is a subtype of conflict. Crawford (2003) refers to a challenge as the pursuit of defined goal. According to Crawford (1984) every game has a goal. But the goal is subordinate to the challenge.

Crawford (2003) indicates, “the point is the challenge, not the goal” (p. 38). Thus, this characterization by Crawford (2003) of challenge as “pitting yourself against some problem” (p. 8) may be more descriptive.

Crawford (2003) argues that a challenge is of two types, a puzzle or a conflict. A puzzle is a challenge without an active opponent; a conflict is a challenge where there is a perceived “active agent against whom you compete” (p. 8). The active agent can be real, simulated, or imagined.

Crawford (2003) further subdivides conflict into competitions and games. In a competition, the rules prohibit the opponents from actively impeding each other. Games, therefore, are a type of conflict that allows players to actively interfere with each other. Thus for Crawford, games are a type of conflict that allows players to “directly interact in such a way as to foil each other’s goals” (p. 8). Crawford (1984) further asserts, “[Conflict] can be direct or indirect, violent or nonviolent, but it is always present in every game” (Chapter 1). To preserve Crawford’s distinction, this study will refer to this form of challenge as *inter-player conflict*. Inter-player conflict is the third possible core component of games from Crawford’s writings to be considered below.

Crawford proposes other essential components in addition to those derived from the two definitions. These elements are *safety* and *interactivity*. Interactivity can be further broken down into *elegant controls*, *key element* and *organic response*.

Safety. Crawford also argues that games must be safe. He states, "A game is an artifice for providing the psychological experiences of conflict and danger while excluding their physical realizations" (Crawford, 1984, Chapter 1). Crawford (2003) cites as an example roller coasters; they give us the illusion of danger with the underlying assurance of safety. Without safety, the conflict becomes real, and therefore, not a game. These safety features, of course, must be designed.

Crawford (2003) does not just mean physical safety. He notes that players invest time in a game. He states,

> Players naturally want to feel that their investment is safe. Without the assurance of safety, players will resort to conservative, careful, plodding strategies—which aren't much fun. Good games permit the player to undo his last move, or play it over, instantly. (p. 32)

This is a different type of safety, but it must also be designed into the game. Thus, safety is another possible core component of games according to Crawford.

The next three possible core components of games come from an analysis of what Crawford (2003) refers to as *interactivity*. Crawford (2003) argues that the unique strength of computers over other media is interactivity. He uses the analogy of conversation to define interactivity as "a cyclic process in which two active agents alternately (and metaphorically) listen, think, and speak" (p. 76). Thus, in terms of a computer game, the game must provide the players the means to express themselves, must understand the player's expression, and must respond appropriately. The conversation is made manifest in a computer game by player inputs through controls, and game system outputs.

Elegant controls. As implied above, controls are the means for players to express themselves (Crawford, 2003, 1984), but even more importantly, according to Crawford (2003), they give the player the "ability to creatively influence the outcome of the game" (p. 87). The dilemma of controls is that, given the input limitations of the computer, they should be relatively simple, yet they should allow the player a wide range of expression (Crawford, 1984). According to Crawford (1984),

> An excellent game allows the player to interact heavily with his opponent, to invest a great deal of his personality into the game. This requires that the game offer the player a large number of meaningful options… Yet, decisions must be inputted, and a large number of options seem to require an extensive and complicated input structure, which could well be intimidating to the player. (Chapter 5)

With thought, Crawford (1984) argues, simplified controls can be designed that allow meaningful options for the player. Therefore, controls should be simple and expressive. To capture this idea, this study shall use the term *elegant controls*. Elegant controls will be included as another possible core component of computer games.

Key element. To accomplish design goal of elegant controls, Crawford (1984) suggests identifying a key element:

> The game designer must identify some key element from the topic environment and build the game around that key element. This key element must be central to the topic, representative or symbolic of the issues addressed in the game, manipulable, and understandable. (Chapter 5)

To illustrate, Crawford provides this example:

> In EASTERN FRONT 1941, I started with the enormous complexity of modern warfare and extracted a key element: movement. Movement dictates the dispositions of the military units. Moving into an enemy's position initiates combat with him. Moving behind him disrupts his supplies and blocks his retreat routes. Moving into a city captures it. Movement is not equitable with all aspects of war; it is, instead, the key element through which many other aspects of war are expressible. It is easily manipulable and immediately understandable. (Chapter 5)

Crawford's design concept of *key element* is related to controls, yet it is distinct from controls. The key element is related to theme, yet it is distinct from theme.

Crawford considers the key element to be important to design a good computer game (Crawford, 1984). Therefore, I will include *key element* for further consideration as a possible core component of games.

Organic response. The reciprocal part of interactivity is the response mechanism of the game. The same properties of elegance that apply to controls also apply to a game's response. Crawford (1984) counsels the designer to exercise restraint:

> Don't make the common mistake of creating cute graphics solely to show off your ability to create cute graphics. Graphics are there for a reason: to communicate. Use graphics to communicate to the user forcefully and with feeling, and for no other reason. Plan functional, meaningful graphics that convey the critical game information while supporting the fantasy of the game. (Chapter 5)

Crawford (1984) further indicates, "The game must be designed in such a way that the information given to the player flows naturally and directly from the screen layout and sound output" (Chapter 4). Thus, the game's response ideally should be perceived as arising naturally from, and supporting the fantasy of the game (Crawford, 2003, 1984). This study will, therefore, characterize this natural information flow under the term *organic response*. Organic response will be included in the consideration of possible core component of computer games.

It should be noted that Crawford (2003) devotes an entire chapter to storytelling and games. He acknowledges a somewhat ambiguous relationship between story and games, however, it would be inconsistent with his analysis to include story as an essential element.

To summarize, I have identified seven possible core components of games from Crawford for consideration in the synthesis phase of this study. These are 1) rules, 2) focused fantasy, 3) inter-player conflict, 4) safety, 5) elegant controls, 6) key element, and 7) organic response.

Greg Costikyan

Greg Costikyan published an influential article, *I Have No Words and I Must Design,* in 1994 and delivered an updated version under the same title in 2002. In the article, Costikyan (2002) defines a game as "an interactive structure of endogenous meaning that requires players to struggle toward a goal" (p. 24). These items will be discussed in the order presented by Costikyan (2002).

Interactivity. By interactive, Costikyan (2002) means "the game state changes in response to [the player's] decision" (p. 11). The player's decision changes the state of the game, and the change of state sets up new conditions for a new decision; thus the game and the player interact. While Costikyan's description of interactivity is less detailed, it is not incongruent with Crawford's (2003) definition of interactivity. Implied is the same need for the player to communicate a decision to the game and the need for the game to perceivably respond (change states). However, this study will retain Costikyan's (2002) term *interactivity* as one of his possible core components of games since he does not make this distinction as explicit.

Goals. According to Costikyan (2002), game interactivity prompts *purposeful decision-making*, that is, decision-making in pursuit of a goal. Costikyan does not explicitly define the term *goal*; however, an implied definition is the game state the player wants to bring to about. Costikyan notes that not all games provide explicit goals. However, explicit goals are not necessary (Costikyan, 1994, 2002). He argues that *Sim City*, for example, allows players to select their own goals, and therefore, still elicits goal-directed behavior from players. Thus, a goal— either provided or player-generated—is a possible core component of computer games.

Struggle. Further, Costikyan (1994; 2002) asserts that goals alone are insufficient. For it to be a game, the player needs to struggle. To struggle is to overcome obstacles or opposition. Although this is similar to Crawford's (2003) idea of conflict, Costikyan (2002) does not limit *struggle* to conflict against an active agent. Struggle can be against passive obstacles, or the forces of nature, for example. Consequently, Costikyan includes puzzles or puzzle elements as part of games since puzzles entail struggle. *Struggle* is another possible core component of games.

Rules. Costikyan (2002) indicates that games have structure. He refers to game structure as "a complex, interacting system that does not dictate outcomes but guides behavior through the need to achieve a single goal" (p. 21). This structure primarily takes the form of *rules*. He notes, "Even kids playing 'let's pretend' feel a need for some structure; they invent rules for themselves, as problems arise" (p. 18). Costikyan acknowledges that some structure is represented in the physical or sensory environment. He provides this example:

> In a boardgame, the structure is mostly contained in the literal rules, although aspects may be contained in the topology of the board, information printed on pieces or cards or other components, etc. The structure is therefore directly perceivable by the player. (p. 19)

Representation. Costikyan (2002) further argues that the rules are distinct from their *representation*—the form which makes the rules perceivable to the senses. He indicates that the rules are "independent from the image bitmaps or 3-D models, the code that displays them onscreen, the animations that indicate to the player that a certain event has occurred" (p. 19). *Representation* is a designable element; therefore, it will be included as a possible core component to inform the synthesis that follows.

Endogenous meaning. Costikyan (2002) defines *endogenous* as “caused by factors inside the organism or system” (p. 22). Thus, endogenous meaning is meaning within the system. According to Costikyan, “A game’s structure creates its own meanings. The meaning grows out of the structure; it is caused by the structure; it is endogenous to the structure” (p. 22). To illustrate, Costikyan provides the following example:

> *Monopoly* money has no meaning in the real world. …Yet when you’re playing *Monopoly*, *Monopoly* money has value. In *Monopoly*, the gaily colored little bills that come with the game are the determinant of success or failure. *Monopoly* money has meaning endogenous to the game of *Monopoly*. (p. 22)

Endogenous meaning also includes the idea that games are fantasy (Costikyan, 2002). As with Crawford (2003), *fantasy* means that even games based on reality are not real (Costikyan, 2002). In short, *endogenous meaning* denotes that games create a reality unto themselves. Endogenous meaning will be included as a possible core component of games.

Costikyan’s 2002 article is substantially the same as the 1994 version. However, there is one item from the earlier version that deserves mention. This element he calls *resources*.

Resources. Resources are things inside the game that you need in order to achieve the goal (Costikyan, 1994). Costikyan (1994) indicates, “Resources can be anything.

Panzer divisions. Supply points. Cards. Experience points. Knowledge of spells. …Information" (Managing Resources). For Costikyan, the need to manage these resources adds complexity, and therefore, interest to the game. Resources appear to be present in every game, even if the primary resource is time. Therefore, *resources* will be included as one of the possible core components of games from Costikyan.

The review of Costikyan has identified these possible core components of games: 1) interactivity, 2) goals, 3) struggle, 4) rules, 5) representation, 6) endogenous meaning, and 7) resources. These elements will be included in the group of possible core components for further comparison and consideration below.

Andrew Rollings and Ernest Adams

According to Andrew Rollings and Ernest Adams (2003) all games have three elements: 1) core mechanics, 2) interactivity, and 3) storytelling and narrative. The element of core mechanics can be characterized as being composed of rules and challenges. The authors further subdivide the element of interactivity into *user interface* and *presentation*. From the discussion of storytelling and narrative, two other possible core components of games can be identified as *story* and *dramatic tension*. These possible core components of games will be discussed below.

Rules and challenge. The element of *core mechanics* is defined by the authors rather broadly. According to Rollings and Adams (2003), the core mechanics are the "rules that define the operation of the game world" (p. 9). These rules not only define how the game world works, they also define the actions that the player may or may not take, as well as defining the challenges, or "obstacles…that the players must overcome to win the game" (p. 35). The authors' discussion includes inherent laws, designed rules of play, and the element of challenge similar to Crawford's (2003) writings. Like Costikyan (2002), however, the term "obstacle" seems to imply that the authors feel that active opposition is not necessary to make the activity a challenge. For clarity, this study will identify the sub-components of *core mechanics*—*rules* and *challenge*—as possible core components of games to be considered in the subsequent phase of reverse engineering in this study.

User Interface. Rollings and Adams (2003) define interactivity as "the way the player sees, hears, and acts within the game's world" (p. 11). Interactivity, according to the authors, has two components: 1) user interface and 2) presentation (Rollings & Adams, 2003). Rollings and Adams (2003) describe the user interface as "the buttons you push to play the game" (p. 12). In other words, *user interface* signifies the means for the player to act within the game for Rollings and Adams (2003).

Presentation. Presentation is the means by which the game presents information to the player usually in the form of graphics and sound (Rollings & Adams, 2003). The authors suggest that presentation should focus more on the functional purpose of images, sound, and other information; aesthetic appeal, though still important, is secondary (Rollings & Adams, 2003). Thus, presentation is more about information design than graphic design. Thus, from *interactivity,* this study draws two possible core components of games—*user interface* and *presentation*—for further consideration below.

Story. Unlike Crawford (2003), Rollings and Adams (2003) assert, "All games tell a story" (p. 10). The authors do not explicitly define *story*, but they provide the following explanation:

> The complexity and depth of that story depends on the game. At one extreme, in adventure games such as *Grim Fandango*, the game is the story. At the other extreme, it's the player who tells the story by the act of playing. (p. 10)

They further argue, "Without a story, or some way for the player to implicitly form his own story, the game simply will not interest the player" (p. 10). Therefore, *story* for these authors would qualify as a possible core component of games.

Dramatic tension. In their discussion, Rollings and Adams (2003) distinguish between storytelling and narrative. They define *narrative* as the "part of the story that is told by [the game] to the player" (p. 10). Therefore, not all games have narrative. Nonetheless, even those games that do not have narrative, according to the authors, have the storytelling element of *dramatic tension*. Rollings and Adams (2003) define *dramatic tension* as "an unresolved issue, problem, or conflict that keeps the reader's attention and makes him want to read on" (p. 10). Since narrative is not a part of all games, it will not be included as a possible core component. However, according to Rollings and Adams, dramatic tension is a part of all games, and therefore, will be included as a possible core component of games.

There are two other elements described by Rollings and Adams (2003) that, in my reading, appear to be connected to storytelling. However, this connection is not made explicitly, so this study will treat them separately. These elements are *game world*, and *player's role*.

Game world. Rollings and Adams (2003) state that "every game, no matter how small, takes place in a world" (p. 55). According to the authors, "A game world is an artificial universe, an imaginary place whose creation begins with the (usually unspoken) words 'Let's pretend…'" (p. 55). The game world can be represented physically or abstractly. According to Rollings and Adams (2003), "Most games have a physical, or at least a visible, manifestation of this world: a set of cards, a board, or an image on a computer screen" (p. 55). However, they also note, "Not all game worlds have a visible component. …A text adventure is [a] game defined by words, the world is created in the player's imagination when he reads the text on the screen" (pp. 55-56). Thus, a possible core component of games for Rollings and Adams (2003) is a *game world*.

Player's role. At first glance, the player's role appears to strain the limits of the search for core components. Rollings and Adams (2003) indicate, "When you're playing a game…you're often playing a *role* of some sort. In *Monopoly*, you're playing a real estate tycoon. In *Goldeneye*, you're playing James Bond" (p. 38). What Rollings and Adams (2003) seem to be describing here is a *persona* or a *character*. Obviously, not all games have characters.

So, why include *player role* as a possible core component of games? It is arguable that in all games the player has a role whether or not it is personified. In any game there is an action or set of actions that only the player can perform. The game does not perform its function without them. These player-dependent actions constitute the player's role. This also seems to be related to Crawford's (2003) *key element* (the action or set of actions the player must master to win the game). Viewed in this way, *player's role* may qualify as a core component of games.

To summarize, this analysis has identified the following potential core components of games from Rollings and Adams (2003): 1) rules, 2) challenge, 3) user interface, 4) presentation, 5) storytelling, 6) dramatic tension, 7) game world, and 8) player's role. These possibilities will be included in the synthesis phase of this study.

Katie Salen and Eric Zimmerman

In *Rules of Play: Game Design Fundamentals*, Katie Salen and Eric Zimmerman (2004) conduct perhaps the most wide-ranging look at games and game design to date. Their approach is to examine various ways to frame games and game design. Thus, much of the book describes different perspectives from which to view and understand games and their design elements. Indeed the authors express that the goal of the book is "not to define, once and for all, what game design is, but to provide critical tools for understanding games" (p. xv). This approach makes it somewhat more difficult to pin down what the authors might consider core components versus peripheral components.

For Salen and Zimmerman (2004), a game can be framed as different types of system. They define a system as, "a set of things that affect one another within an environment to form a pattern that is different from any of the individual parts" (p. 50). The *game as played* is an experiential system and can be open or closed. In its cultural context, the game is a cultural system and is an open system. The *game as designed* is a formal system and it is closed (Salen & Zimmerman, 2004). In this respect their definition is congruent with Crawford's (2003): a game (as designed) is self-contained and is defined by rules. To stay focused on the purpose of this dissertation therefore, this study will confine itself to the aspects of the game as a designed, closed system.

For Salen and Zimmerman (2004), a game "is a system in which players engage in an artificial conflict, defined by rules, that results in a quantifiable outcome" (p. 80). As with Crawford, this study will not include *system* as a component. The remaining elements of their definition, however, will be examined.

Artificial reality. For Salen and Zimmerman (2004), the term *artificial* indicates that "games maintain a boundary from so-called 'real-life' in both time and space" (p. 80). To describe this idea, Salen and Zimmerman adopt the term *magic circle* from Huizinga (1970). To enter a game is to step out of *real life* and enter a *magic circle*, a temporary reality with its own boundaries and rules (Salen & Zimmerman, 2004). The authors note, "within the magic circle, special meaning accrue and cluster around objects and behaviors. In effect, a new reality is created…" (p. 96). Thus, to design a game is to design an alternate reality. Although the term *magic circle* is very descriptive, this study will circumscribe *artificial* and *magic circle* more concretely and simply in the term *artificial reality*. Artificial reality will be included as a possible core component of computer games.

Conflict. Salen and Zimmerman (2004) define conflict as a "contest of powers" (p. 80). They concur with Crawford (2003) that conflict is an element of all games and that conflict can by direct or indirect (Salen & Zimmerman, 2004). Like Costikyan (2002), however, Salen & Zimmerman (2004) do not limit the scope of conflict to interaction with an active agent. Further, Salen and Zimmerman (2004) indicate that a game can contain multiple forms of conflict. Thus, the synthesis phase of this study will include *conflict* as a possible core component of games.

Operational and constitutative rules. According to Salen and Zimmerman (2004), rules "constitute the inner, formal structure of the game" (p. 125). The authors describe three different types of rules: 1) operational rules, 2) constituative rules, and 3) implicit rules. The *operational rules* Salen and Zimmerman (2004) define as, "the 'rules of play' of a game. They are what we normally think of as rules: the guidelines players require in order to play" (p. 130). Salen and Zimmerman (2004) define *constituative rules* as, "the underlying formal structures that exist 'below the surface' of the rules presented to players" (p. 130). This appears similar to Crawford's (2003) distinction between inherent and administrative rules. Salen and Zimmerman (2004) also define *implicit rules* as, "the 'unwritten rules' of a game" (p. 130). They further elaborate, "These rules concern etiquette, good sportsmanship, and other implied rules of proper game behavior" (p. 130).

However, they indicate that the rules that establish the identity of a game are the *operational rules* and the *constituative rules* and not the implicit rules (Salen & Zimmerman, 2004). The distinction between operational and constituative rules that Salen and Zimmerman (2004) make is more deliberate than that made by Crawford, therefore, both *operational rules* and *constituative rules* will be considered as possible core components of games in the subsequent phase.

Quantifiable outcome. Salen and Zimmerman (2004) also assert that another defining element of games is a *quantifiable outcome*. They describe *quantifiable outcome* as follows,

> Games have a quantifiable goal or outcome. At the conclusion of a game, a player has either won or lost or received some kind of numerical score. A quantifiable outcome is what usually distinguishes a game from less formal play activities. (p. 80)

It should be noted that *goal* and *outcome* appear to be used interchangeably. Nonetheless, this study will use *quantifiable outcome* as Salen and Zimmerman's (2004) primary term for this possible core component of games to be included for further consideration.

Immediate feedback. One of the distinguishing features of computer games according to Salen and Zimmerman (2004) is *immediate but narrow interactivity*. By *immediate* the authors mean immediate feedback. They indicate, "One of the most compelling qualities of digital technology is that it can offer immediate, interactive feedback" (p. 87). Immediate feedback will be included as a possible core component of games from Salen and Zimmerman.

Narrow input. By *narrow interactivity,* Salen and Zimmerman (2004) mean restricted input. Similar to Costikyan (2002), *interactivity* is evidenced for Salen and Zimmerman (2004) when "every action results in a change affecting the overall system" (p. 58). Using a fighting game as an example, they indicate, "The lightning-quick response of the program, paired with the streamlined control input, contribute to the uniquely meaningful play of a well-designed fighting game" (p. 87). Thus, another possible core component of games is narrow input. Components identified to this point from Salen and Zimmerman (2004) include 1) artificial reality, 2) conflict, 3) operational rules, 4) constituative rules, 5) quantifiable outcome, 6) narrow input, and 7) immediate feedback.

Uncertainty. According Salen and Zimmerman (2004), "uncertainty is a key component of every game" (p. 189). Citing Richard Epstein's *Theory of Gambling and Statistical Logic*, Salen and Zimmerman (2004) discuss three degrees of uncertainty: *uncertainty*, *risk*, and *certainty*. Certainty is when the outcome is known or highly predictable such as playing Tic-Tac-Toe when both players know the patterns that will always result in a draw. The initial move may be uncertain but the eventual outcome is certain (Salen & Zimmerman, 2004). Salen and Zimmerman (2004) indicate that Epstein's category of risk "refers to a situation in which there is some uncertainty but the players know the nature of the uncertainty in advance" (p. 175). In other words, the players generally know the odds of winning or losing. Rock, Paper, Scissors would be an example. The authors describe Epstein's category of uncertainty as "a situation in which players have no idea about the outcome of the game" (p. 175) and cite Chess as an example. Salen and Zimmerman (2004) also indicate "most games possess some combination of risk and uncertainty" (p. 175). They later appear to use the term *uncertainty* to include both *risk* and *uncertainty* as defined by Epstein. Thus, this study will use the term *uncertainty* to include both categories as well. In addition, I will include *uncertainty* in the subsequent reverse engineering phase.

Core mechanic. Salen and Zimmerman's (2004) use of *core mechanic* is different from Rollings and Adams (2003). Their usage of *core mechanic* is very similar to Crawford's (1984) concept of *key element*. For Salen and Zimmerman (2004) "a core mechanic is the essential play activity players perform again and again in a game" (p. 316). They further indicate, "The core mechanic is the essential nugget of game activity" (p.

316). It can be a single activity such as running or a compound activity such as simultaneously moving and shooting (Salen & Zimmerman, 2004). For the authors the core mechanic is essential to all games; therefore, I will include *core mechanic* for further consideration as a potential core component of games.

Rewards and punishments. Salen and Zimmerman (2004) borrow from B.F. Skinner's theory of *operant conditioning* to define rewards and punishments. Rewards include *positive reinforcements*, or receiving something pleasant, and *negative reinforcements*, or the removal of something unpleasant (Salen & Zimmerman, 2004). Salen and Zimmerman (2004) indicate that punishment is "the addition of something unpleasant" (p. 345). Salen and Zimmerman (2004) also note that, in general, rewards should be more common than punishments. Another possible core component of games for Salen and Zimmerman is *rewards and punishments*.

Narrative descriptors. Salen and Zimmerman (2004) note that "the intersection of the terms 'narrative' and 'game' has been surprisingly contentious in the study and design of games" (p. 379). For Salen and Zimmerman (2004), the question is not, "are games stories?" Rather, the issue is "how games construct narrative experiences" (p. 383). Citing Marc LeBlanc, Salen and Zimmerman (2004) concur that "game narratives can be *embedded* or *emergent*" (p. 383). *Embedded narrative* is the pre-scripted, pre-generated storytelling inside the game; it is relatively unchangeable (Salen & Zimmerman, 2004). *Emergent narrative* is the story that the player generates by playing the game (Salen & Zimmerman, 2004). This idea is similar to Rollings and Adams' (2003) thoughts on storytelling. This poses a problem for the discussion of core components. On the one hand, all games would have emergent narrative. But is emergent narrative a design component or a property or outcome of a played game?

A better candidate for a possible core component of games is an element that Salen and Zimmerman (2004) call *narrative descriptors*. According to Salen and Zimmerman (2004), "narrative descriptors are representations, which means that they are depictions of one or more aspects of the game world" (p. 399). Narrative descriptors can be graphics, music, sound effects, text, video, animations, etc. (Salen & Zimmerman, 2004). According to Salen and Zimmerman (2004), "thinking in terms of narrative descriptors means framing the elements inside and outside [packaging, etc.] of a game as objects that communicate the story" (p. 399). Thus, narrative descriptors are not a story, but they facilitate the construction of story. These are design elements, and according to Salen and Zimmerman (2004), are present in all games, therefore, I will include *narrative descriptors* for further consideration as one of the possible core components of games.

In summary, the possible core components of games identified from Salen and Zimmerman (2004) are 1) artificial reality, 2) conflict, 3) operational rules, 4) constituative rules, 5) quantifiable outcome, 6) narrow input, 7) immediate feedback, 8) uncertainty, 9) core mechanic, 10) rewards and punishments, and 11) narrative descriptors. These possible core components of games are compared with those of other game designers in Table 3.

Table 3.

*Comparison of potential core components by game designer**

Crawford	Costikyan	Rollings & Adams	Salen & Zimmerman
Rules	Rules	Rules	Operational Rules Constituative Rules
Focused Fantasy	Representation	Game World	Artificial Reality
Inter-player Conflict	Struggle	Challenge	Conflict
Elegant Controls	Interactivity	User Interface	Narrow Input
Key Element		Player's Role	Core Mechanic
Organic Response		Presentation	Immediate Feedback
		Dramatic Tension	Uncertainty
		Storytelling	Narrative Descriptors
			Rewards & Punishments
			Quantifiable Outcome
	Goals		
	Endogenous Meaning		
	Resources		
Safety			

* Terms in the same row indicate similar meanings.

Analysis of Game Components from Selected Game Theorists

In addition to practicing game designers, academic theorists are also writing about play and games; however, much of that literature focuses on the psychology or sociology of games rather than the design of games. Nonetheless, there are some theorists who propose structural elements of games that are also cited by the game design community. Notable among these are Johan Huizinga, Elliot Avedon and Brian Sutton-Smith, and more recently, Jesper Juul. These authors will also be included in the analysis of possible core components of games.

Johan Huizinga

According to Salen and Zimmerman (2004), Johan Huizinga's work *Homo Ludens* (Man the Player) was "a groundbreaking study of the play element in culture" (p. 75). Although Huizinga (1970) focuses primarily on the phenomenon of play, he also identifies essential elements that apply to games. These elements are discussed below.

Temporary world. According to Huizinga (1970) play occurs in a *temporary world*. This temporary world is limited in time and space (Huizinga, 1970). Further, it sits outside of "real" life; there is an element of imagination or pretense that nonetheless is treated seriously (Huizinga, 1970). *Temporary world* will be included as possible core component of games.

Tension. According to Huizinga (1970), *tension* means “uncertainty, chanciness” (p. 29). For Huizinga (1970) it is this element that excites player action toward an implied element, the outcome or goal. *Tension* will be included as possible core component of games.

Rules. Huizinga (1970) states, “All play has its rules” (p. 30). The rules, according to Huizinga (1970), “determine what ‘holds’ in the temporary world” (p. 30). Huizinga (1970) further asserts, “The rules of a game are absolutely binding and allow no doubt” (p. 30). *Rules* will be included as possible core component of games.

Test of prowess. Play and games provide for a test of prowess (Huizinga, 1970). Through the test of prowess, Huizinga (1970) suggests, the player demonstrates “his courage, tenacity, resources, and last but not least, his spiritual powers—his ‘fairness’; because, despite his ardent desire to win, he must still stick to the rules of the game” (p. 29). *Test of prowess* will be included as possible core component of games.

To summarize, this review has identified these possible core components from Huizinga: (a) temporary world, (b) tension, (c) rules, and (d) test of prowess. These will also be included for further consideration in the synthesis that follows.

Elliott Avedon and Brian Sutton-Smith

In *The Study of Games*, Elliott Avedon and Brian Sutton-Smith (1971) define a game as "an exercise of voluntary control systems in which there is an opposition between forces, confined by a procedure and rules in order to achieve a disequilibrial outcome" (p. 7). The term *voluntary control systems* refers to the motor control of the player and therefore, does not qualify as a design element. However, the authors include four other elements that do warrant discussion. These are *opposition of forces*, *procedure*, *rules*, and *disequilibrial outcome*.

Opposition. Avedon and Sutton-Smith (1971) identify *opposition of forces* (opposition) as an element of games. They indicate that opposition of forces can occur as "antithesis between players," as "impersonal obstacles" or as the player "mentally pits one aspect of himself against another" (p. 7). Avedon and Sutton-Smith (1971), thus expand the notion of opposition to include internal conflict, or man versus self as compared to previous authors. *Opposition* will be included as a possible core component of games.

Procedure. Procedure is the action or set of actions allowed in the game (Avedon & Sutton-Smith, 1971). Further, it is a constrained range of action. Procedure is another possible core component of games from Avedon and Sutton-Smith (1971).

Rules. The *rules* are not defined by Avedon and Sutton-Smith (1971) in the discussion of the definition of a game. They are however defined in a later chapter. Avedon (1971) defines *rules* as "fixed principles that determine conduct and standards of behavior" (p. 422). This seems to correspond to the operational rules as described by Salen and Zimmerman (2004). Therefore, rules will be identified as a possible core component of games from Avedon and Sutton-Smith.

Disequilibrial outcome. By *disequilibrial outcome*, Avedon and Sutton-Smith (1971) mean that the outcome is not the same for all parties; there is a winner and a loser. This is very similar to *quantifiable outcome* as proposed by Salen and Zimmerman (2004). Consequently, I will include *disequilibrial outcome* in the synthesis that follows.

Other possible core components are discussed by Avedon (1971) in a later section of the book. Avedon (1971) reviews structural elements of games proposed from the perspective of mathematicians, sociologists, and psychiatrists, and from the field of recreation. Two of these, *procedure* and *rules*, have already been described. Another, *number of required participants*, would appear to fit in the category of rules, and therefore, will not be included. Two others, *abilities and skills* and *interaction patterns*, are described from the player's perspective rather than from a design perspective and also will not be included as possible core components of games. The remaining five structural elements of games described by Avedon (1971) will be discussed below. (Avedon briefly defines these elements; he does not discuss them at length.)

Goal. Avedon (1971) identifies *purpose of the game* as an element of games and defines it simply as the "aim or goal" (p. 422). An example from chess would be to checkmate the opponent. For simplicity, this study will use the term *goal* to refer to this possible core component. Further, it will also be in the synthesis that follows.

Role. Avedon (1971) defines *roles of participants* (role) as "indicated functions and status" of the players. Examples of roles are goalkeeper, center, etc. (p. 422). Roles are a possible element of design; therefore, *role* will be included in the synthesis phase of this study.

Pay-off. The *results or pay-off* (pay-off) according to Avedon (1971) are the "values assigned to the outcomes of the action" (p. 423). For example, a field goal in basketball is worth two points while a foul shot is worth one point. P*ay-off* will be included as another possible core component of games included for further synthesis.

Setting. Avedon (1971) defines the *physical setting* as the "man-made or natural facility in which action take place" (p. 425). Avedon (1971) takes this element from the field of recreation, thus its emphasis on *physical*. Since *physical setting* is a subset of the more general term *setting*, and since one of Avedon's examples does not have a specific physical setting, this study will prefer the term *setting* to name this possible core component of games from Avedon (1971).

Equipment. According to Avedon (1971) *required equipment* (equipment) indicates the "man-made or natural artifacts employed in the course of action" (p. 425). This would include items such as tennis rackets, balls, net, etc. It is similar to Costikyan's component of *resources*; therefore, I will include equipment as a possible core component from Avedon (1971).

To summarize, this analysis has identified the following possible core components of games from Avedon and Sutton-Smith (1971) and Avedon (1971): (a) opposition, (b) procedure, (c) rules, (d) disequilibrial outcome, (e) goal, (f) role, (g) pay-off, (h) setting, and (i) equipment. These possible core components will be part of the synthesis portion of this study.

Jesper Juul

Juul (2003) asserts that there are six elements of games. According to Juul (2003), these elements are (a) rules, (b) variable, quantifiable outcome, (c) valorization of outcomes, (d) player effort, (e) player attachment to outcome, and (f) negotiable consequences. The latter two do not fit the search criteria: *player attachment* refers to the player's state of mind, and *negotiable consequences* refers to the possibility that players may decide to play the game for real-world stakes.

Rules. Juul (2003) states, "Games have rules" (p. 36). The rules are also fixed; that is, according to Juul (2003), "The rules of games have to be sufficiently well defined that they can either be programmed on a computer or sufficiently well defined that you do not have to argue about them every time you play" (p. 36). Thus, a possible core component of games from Juul (2003) is *rules*.

Variable, quantifiable outcome. For Juul (2003) *variable* means that "the game must provide different possible outcomes" (p. 36). Many games, for example, can result in a win, loss, or draw. By *quantifiable*, Juul (2003) means that the outcome "is designed to be beyond discussion" (p. 37). Therefore, another possible core component of games is *variable, quantifiable outcome*.

Valorization of outcomes. According to Juul (2003) *valorization of outcomes* "simply means that some of the possible outcomes of the game are better than others" (p. 37). In other words, a value is assigned to a given outcome; these values can be positive, negative or neutral. *Valorization of outcomes* is another possible core component of games from Juul (2003) to be included in the synthesis phase.

Player effort. Juul (2003) indicates that "player effort is another way of stating that games are challenging, or that games contain a conflict, or that games are 'interactive'" (p. 37). Although this definition seems rather broad and contains possible core components identified above, I will include *player effort* in the subsequent synthesis phase of this study.

In summary, the study has identified four possible core components of games as described by Juul (2003) that will be included in the synthesis phase of the reverse engineering process. These possible components are (a) rules, (b) variable, quantifiable outcome, (c) valorization of outcome, and (d) player effort. This concludes the analysis of design elements from game designers and game theorists.

The complete set of possible core components are arranged For purposes of comparison and co, the possible core components of from game theorists are arranged with possible core components from game designers in Table 4.

Table 4.

*Final comparison of potential core components of games by author**

Crawford	Costikyan	Rollings & Adams	Salen & Zimmerman	Huizinga	Avedon & Sutton-Smith	Juul
Rules	Rules	Rules	Operational Rules Constituative Rules	Rules	Rules	Rules
Focused Fantasy	Representation	Game World	Artificial Reality	Temporary World	Setting	
Inter-player Conflict	Struggle	Challenge	Conflict	Test of Prowess	Opposition	Player Effort
Elegant Controls	Interactivity	User Interface	Narrow Input			
Key Element		Player's Role	Core Mechanic		Procedure	
Organic Response		Presentation	Immediate Feedback			
			Quantifiable Outcome		Disequilibrial Outcome	Variable, Quantifiable Outcome
		Dramatic Tension	Uncertainty	Tension		
			Rewards and Punishments		Pay-off	
		Storytelling	Narrative Descriptors			
	Goals				Goal	
	Endogenous Meaning					Valorization of Outcome
	Resources				Equipment	
					Role	
Safety						

* Terms in the same row indicate similar meanings

CHAPTER 5—SYNTHESIS OF CORE COMPONENTS OF COMPUTER GAMES

In this section, I will postulate a set of core components of computer games derived from the possible core components identified above. Table 4 shows individual author's core components vertically and groups similar terms horizontally. It is apparent that there is a great deal of agreement. It is also apparent that, at least terminologically, that there is some ambiguity. For example, is the proper term *goal*, or *challenge* or *outcome*?

One of the reasons for this ambiguity appears to be that these terms are interrelated. For this reason, it does not seem beneficial to debate the relative merits of each definition. It may be that, rather than defining them individually, they can be defined in a nested hierarchy that, therefore, also illustrates their relationships. This would be analogous to identifying systems and subsystems. Given that a game is a system (Costikyan, 2002; Crawford, 2003; Juul, 2003; Salen & Zimmerman, 2004), this may be the most appropriate approach. It would also be beneficial, to the extent possible, to select terms that also describe the player/game relationship. Further, it is understood that there will be subcomponents and properties that are not included in these definitions; that task goes beyond the purpose of this dissertation. Therefore, I propose that games are composed of four composite core components: (a) *meaningful challenge*, (b) *self-consistent setting*, (c) *player presence*, and (d) *embedded helps*.

Meaningful Challenge

A *meaningful challenge* is an attainable goal of endogenous value that entails conflict constrained by operational rules and limited resources. Therefore, a *meaningful challenge* is composed of these elements, and these elements interrelate to create a *meaningful challenge*.

Attainable goal

I concur with Crawford (2003) that "the point is the challenge, not the goal" (p. 38). Going to the grocery story is a goal, but it is not normally a challenge. However, going to the grocery store could be a challenge if the other elements were present. Of course, there could also be no challenge without a goal.

The goal is the desired future outcome or end state of the game. Until the end state is achieved it is a goal. Once the goal is achieved, it is an outcome; however, at that point, the challenge ceases, and the game is over. It is the goal that entices the player forward, therefore, the most appropriate term is *goal* rather than *outcome*. Thus, *goal* is a component of *meaningful challenge*.

Attainable applies both to the game structure and to player perception. For the game it means that the challenge is scaled, or scaleable to the ability level of the player. Ideally, as player ability increases, the level of challenge also increases correspondingly (Crawford, 1984; Rollings & Adams, 2003; Salen & Zimmerman, 2004).

For the player, *attainable* is the perception that it is possible to accomplish the goal. Crawford (1984) refers to this as the "illusion of winnability" (Chapter 6). It is an illusion because the game does not have to be literally "winnable" (Chapter 6). According to Crawford (1984), "if the player believes failures to be attributable to correctable errors on his own part, he believes the game to be winnable and plays on in an effort to master the game" (Chapter 6). If the goal is not perceived as attainable, it not perceived as meaningful.

Endogenous value

While *endogenous meaning* from Costikyan (2002) is adequate; the term *meaning* does not necessarily connote desirability. The idea of *valorization* (Juul, 2003), or *value*, does imply desirability or esteem. Therefore, I will define *endogenous value* as desirability or esteem within the game system. Endogenous value also goes to the notion of the *magic* *circle* from Salen and Zimmerman (2004). When players enter the magic circle of the game, they also adopt temporarily the value system of the game (Huizinga, 1944/1970; Salen & Zimmerman, 2004). If the goal has value within the context of the game, it is meaningful.

Conflict

Conflict is the component that makes a goal a challenge. Conflict need not be limited to inter-player conflict. Conflict can result from players' own lack of knowledge and/or ability within the game (internal conflict), or from active opposition from other players. From the game, conflict can come from passive obstacles such as terrain, unpredictable equipment such as dice, and/or from active opposition by game agents (often called non-player characters, or NPC's). Thus, conflict is active or passive, internal or external opposition to the player's goals and behaviors.

Value also relates to conflict. It can be assumed that if the goal is valuable, then other agents will value its attainment as well. The amount of value tends to increase the amount of conflict players will expect. At the same time, it can be true that the amount of conflict increases the perceived value. If these are out of balance however, players can become disappointed and disengage (Crawford, 2003; Rollings & Adams, 2003; Salen & Zimmerman, 2004).

I would argue that *uncertainty* is a property of conflict. It is the presence of conflict that produces the possibility of alternative outcomes. By manipulating conflict, you manipulate uncertainty. Conflict is manipulated through the *operational rules* and the availability and quality of *resources*.

Operational rules

The separation of the rules into the "rules of the game," or *operational rules*, and the "rules of the game world," or *constituative rules* (Salen & Zimmerman, 2004), is a helpful distinction. The rules of the game define player actions and interactions (Avedon, 1971; Crawford, 2003; Salen & Zimmerman, 2004); they can also change situationally. In football, for example, there are different rules for the situation of punting, and different rules for the situation of the kick-off. Although other authors noted or implied this distinction, the term *operational rules* from Salen & Zimmerman (2004) seems to fit best. Operational rules fit within *meaningful challenge* because it is through the operational rules that you can manage and manipulate conflict. Operational rules manage conflict by allowing certain behaviors, prohibiting others, and by providing for compensatory measures, or penalties, for rule infractions.

Limited resources

I agree with Costikyan (1994) that limited resources are part of games. Salen & Zimmerman (2004) also note that games employ sub-optimal means. *Limited resources* is a subcomponent of *meaningful challenge* because acquiring and/or mastering the use of the resources is part of the challenge. Further, the structuring of resources also manipulates conflict. In many games, acquiring a new weapon allows you to take on different, usually more powerful, enemies. This also introduces a possible internal conflict: for example, "Which weapon do I use in this situation?" Thus, the judicious design of resources is another way to shape challenge and conflict.

This structural definition of *meaningful challenge* resolves the ambiguities and overlap of the individual definitions while maintaining and interrelating the essential components. While there other properties and sub-components that are worthy of discussion, these go beyond the scope of this dissertation. Therefore, I submit that *meaningful challenge* is a core component of computer games.

Self-consistent Setting

Although *focused fantasy* as defined by Crawford (1984) is the more elegant term, it is also subject to misinterpretation. The term *game world* is another term that has merit; however, this term may lead the designer to assume that a 3-D realistic environment is necessary. A more general term that can imply both the simple as well as the richly detailed representation is *self-consistent setting*. The term *self-consistent* also implies that everything necessary for the experience is present in the system and works well together. Therefore, I will use the term *self-consistent setting* as the second core component of games. *Self-consistent setting* is defined as a co-constructed alternate reality defined by constituative rules, and represented thematically.

Co-constructed alternate reality

The *self-consistent setting* is co-constructed in that the game designer cannot deliver "reality;" therefore, the designer constructs a subset of reality (Crawford, 1984). The term *co-constructed* encapsulates *focused fantasy* but is, hopefully, not as open to preconceptions as is fantasy. As Crawford (1984) indicates, a property of this subset is that it should be focused. The player, through imagination, supplies whatever else is necessary to complete the "construction" of the setting.

The notion of *alternate reality* acknowledges that the game is outside of "real life" (Huizinga, 1944/1970; Salen & Zimmerman, 2004) yet is accepted, for the term of the game, as reality. This is analogous to the idea of the *magic circle* (Huizinga, 1944/1970; Salen & Zimmerman, 2004). Salen & Zimmerman (2004) state, "Within the magic circle, special meaning accrue and cluster around objects and behaviors. In effect, a new reality is created…" (p. 96).

Constituative rules

According to Salen & Zimmerman (2004), the constituative rules "are the underlying formal structures" (p. 130). By way of interpretation, the constituative rules define the boundaries of the *self-consistent setting*: the "natural" objects or organisms that may be present, and the "natural" laws, or forces that operate within the alternate reality of the game. In games with people or non-player characters, constituative rules would include the cultural norms or rules.

Thematic representation

It is an important distinction that the constituative rules are not the representation of the game world (Costikyan, 2002; Rollings & Adams, 2003; Salen & Zimmerman, 2004). To the extent possible, the constituative rules are communicated by representing them *thematically* (Rollings & Adams, 2003; Salen & Zimmerman, 2004). The notion of theme is chosen because it connotes both the topic, as well as a consistent style of representation.

Thematic representation relies on *narrative descriptors* as discussed by Salen & Zimmerman (2004). Salen & Zimmerman (2004) indicate,

> Representations in games do not exist in isolation from the rest of culture. They rely on conventions drawn from narrative genres in other media. Although the playgrounds of games may offer fictive and fantastical spaces, these spaces are almost always familiar in some way to players. The deep space of Asteroids is not something any of us have experienced directly, but it is part of a genre-based universe found in the stories of science fiction writers and astrophysicists. Players can appreciate the narrative of the game even if they have never piloted a space ship in a field of asteroids, because of the familiar conventions of its representation. (p. 401)

The chosen theme dictates, or should dictate, the narrative descriptors that represent the *self-consistent setting*. Not simply for artistic unity, although that is desirable as well (Crawford, 1984), but because the theme communicates or suggests the constituative rules on many levels (Salen & Zimmerman, 2004). For example, in a darkened mansion with eerie music, it would be reasonable to see a ghost pass through walls; whereas in a similar mansion with sunlight streaming through the windows and pleasant music playing, walls would be expected to be impermeable. It stands to reason that to introduce extraneous narrative descriptors is to communicate another set of possibly contradictory rules, and therefore confuse the player. Certainly, themes can and have been mixed successfully; however, there is usually an additional constituative rule (such as time travel, magic, the holodeck, for example) that explains or rationalizes the combination of themes.

The structural definition of *self-consistent setting* accounts for important components of games and demonstrates their interrelationship as a functional composite. The definition of *self-consistent setting* does not eliminate other subcomponents or properties, but rather, provides a framework for their inclusion and discussion. Therefore, I submit that *self-consistent setting* is a core component of computer games.

Player Presence

The core component, which I shall term *player presence,* was somewhat more difficult to define because the input and output of interactivity seemed to emphasize the mechanical and computational side of computer games. To say that you are designing controls and feedback mechanisms is accurate on one level, but in some ways it misses the mark. You are designing the means for the player to be present in the world of the game: to act, to speak, to create meaning (Costikyan, 1994; Crawford, 2003; Salen & Zimmerman, 2004). Salen & Zimmerman (2004) assert that when one enters the magic circle of the game the game token is no longer a piece of plastic, the game token becomes "you." Achieving this quality of player presence, is crucial to the success of the game (Crawford, 2003, 1984; Rollings & Adams, 2003; Salen & Zimmerman, 2004).

Player presence should not be confused with the character or persona a player may have in a game. As indicated previously, the player's role in terms of a character or persona is optional. Certainly, the player's feeling of presence may be enhanced through a persona. However, the purpose of a persona seems to be primarily to serve as a narrative descriptor to communicate cultural and physical constituative rules, and therefore *persona* would be a subcomponent of thematic representation.

I would argue that *player presence* is what is often referred to as *immersion*. It goes beyond the notion of *suspension of disbelief*. The player's suspension of disbelief is necessary, but it is a threshold condition. Immersion occurs when players imaginatively invest themselves in the game. Therefore, immersiveness is not in the aesthetic quality, or realism of the game's output but again, in the *imaginative perception of being present* in the game's world (Crawford, 2003; Rollings & Adams, 2003; Salen & Zimmerman, 2004). Certainly, aesthetics are important, but they are not sufficient to sustain engagement (Crawford, 2003; Rollings & Adams, 2003). But the player's role as an action or set of actions that only the player can perform—the ability, according to Crawford (2003), to "creatively influence the outcome of the game" (p. 85)—is essential (Crawford, 1984; Salen & Zimmerman, 2004).

Core Performance

This concept of creatively influencing the game is best encapsulated by Crawford (1984) and Salen and Zimmerman (2004) in the terms *key element* and *core mechanic* respectively, referring to the central action or integrated actions the player must master to win the game. A similar idea is also referred to by Avedon (1971) as *procedure*. To reduce the confusion of terms, I will coin the term *core performance* to indicate a central, defined action the player must perform. From the perspective of computer games, it is easy to get caught up in the need to design input systems and output systems. Looking ahead, however, to the more abstract notion of designing engaging experiences, it becomes apparent that *core performance* is the more important than controls, since not all situations will need mechanical systems, but will require participant performance.

Computer game players influence the game through the controls, and perceive their presence in the game through the discernable response of the game system (Rollings & Adams, 2003; Salen & Zimmerman, 2004). In other words, the player feels present in the game through a tight continuous cycle of player action/game response—by acting through the controls and experiencing the manifestation of those actions in the game's world. Therefore, *player presence* is designed through the *core performance* which must be further translated into *elegant controls* and *immediate cause-effect signifiers*.

Elegant controls

As noted above a game's controls should be both simple and yet expressive (Crawford, 2003). A suitable term for this quality is *elegant*. The controls are the input devices used by the game. As discussed above, elegant controls provide the means for the player to act within the game. It is not that the controls cannot be complex, but that the complexity is warranted for the fantasy of the game (Crawford, 1984). There is an inverse relationship between complexity of controls and the pace of the game; where the demands of the game on the player come faster, the controls (and the *core performance*), in general, should be simpler (Crawford, 1984). In slower paced games, the controls can be (but need not be) more complex. In all cases elegant controls are the ideal.

A qualitative criteria for elegant controls is that using the controls should recede into the background of the player's consciousness, while player action in the game moves into the foreground (Rollings & Adams, 2003). Initially, learning the controls often takes conscious effort. Ideally, using the controls should become like walking, or riding a bike; they can be done without consciously thinking about them, freeing up the conscious mind to deal with other matters—like winning the game.

Immediate cause-effect signifiers

The term *immediate cause-effect signifiers* is a more specific reference to the response of the game to player input. Salen & Zimmerman (2004) appear to refer to both immediate feedback and discernable outcomes synonymously. Outcomes later seem to be related to the goal or eventual outcome of the game (Salen & Zimmerman, 2004). In another section, Salen & Zimmerman (2004) discuss feedback in terms of other inputs that are more analogous to rewards and punishments. Thus, feedback and outcomes are misinterpretable.

However, *immediate cause-effect signifier* should be understood narrowly to refer to a tight cause-effect relationship of player action and its effect in the game. For example, in a shooting game, if the player "pulls the trigger" the player should immediately be informed that shot was fired by a visual flash from the muzzle, for example, or sound of a gunshot, or both. Of course, this should continue through the entire effect of the action; representing the initial effect through the terminal effect of the action—for example, whether or not the player's shot hit the target. It is through this coupling of player action and its effect in the game that *player presence* is achieved.

In summary, the core component of *player presence* is at the interface between the player and the game system. For a computer game, *player presence* is designed through *elegant controls* and *immediate cause-effect signifiers;* through these means, the player executes, and evaluates the effect of, the *core performance*. It is the design of these elements that constitute the core component of *player presence* in computer games. Therefore, *player presence* is defined as the means to make your decisions and actions manifest in the setting through the core performance and its observable effect in the game.

Embedded Helps

The core component of *embedded helps* is not obvious; it is not specified by any of the authors, although I would assert that it is implied. I believe it is implied in part because the forms of *embedded helps* are quite varied; thus this categorization would not be readily apparent. Further, it seems that some of these *embedded helps* seem so "natural" to the game that they are not recognized for what they are. Also, they are often included in other categories such as interface or feedback for example. Finally, *embedded helps* appear to play a dual role; that is, because they are helps, and therefore desirable, they can also be used to manipulate conflict. Nonetheless, I submit that their characterization as *embedded helps* more accurately expresses their essential nature. By *embedded* I mean that the helps are placed within the *self-consistent setting* of the game, and importantly, they are consistent with the setting's theme. *Embedded helps* appear natural because, to the extent possible, they too are represented thematically. The term *helps* means things that assist, encourage, or guide the player to toward the goal. *Embedded helps* include, but may not be limited to, *rewards and punishments*, *recoverability mechanisms*, and *information devices*.

Rewards and punishments

Salen & Zimmerman (2004) citing Hallford and Hallford (2001) place rewards into four categories:

1. Rewards of glory. Rewards of glory are acknowledgements of the successful resolution of challenges and sub-challenges within the game. These rewards often come at the completion of a game level, or side quest, or at the end of the game (Hallford & Hallford, 2001). Where other rewards do benefit the player in terms of game play, rewards of glory do not (Hallford & Hallford, 2001; Salen & Zimmerman, 2004). Rewards of glory do, however, have a positive effect on players' emotions.
2. Rewards of sustenance. Hallford and Hallford (2001) indicate that rewards of sustenance, for example, "include health packs that heal injuries, mana potions that increase a player's magical abilities, high-tech armor that shields a player…" (p. 158). Rewards of sustenance give the game character life, energy and protection within the game world.
3. Rewards of access. According to Hallford and Hallford (2001), rewards of access "allow a player access to new locations or resources that were

previously inaccessible…" (p. 159). Examples include door keys and passwords.

4. Rewards of facility. Hallford and Hallford (2001) state that rewards of facility "enable a [player] to do things they couldn't do before or enhance abilities they already possess" (p. 159). The power pellet that allows Pac-Man eat the ghosts instead of being killed by them is a good example.

It seems obvious that these rewards provide significant help to players, yet they usually appear to be natural within the *self-consistent setting* of the game, and therefore possibly not perceived as help because they are not external.

Punishments are only lightly dealt with by Salen & Zimmerman (2004). Punishments indeed have a dual nature. If the player is punished, it is not perceived as help, although it does work as part of conflict. However, if an opponent is punished, the result is often beneficial to the player. Salen & Zimmerman (2004) indicate that, in general, rewards should be emphasized in favor of punishments. Paradoxically, however, punishments, or even failure, when combined with *recoverability* (see below), though not pleasant, can be considered a form of help as they pinpoint for the player weaknesses in strategy or performance. Games consistently cause players to fail (Crawford, 2003; Rouse, 2001); recoverability mechanisms then allow players to learn from their mistakes and continue play.

Recoverability mechanisms

According to Crawford (2003),

> Good games permit the player to undo his last move, or play it over, instantly. The quicker and more easily the player can correct a mistake, the safer he will feel and the more exploratory and playful his play will be. (p. 32)

The mechanisms mentioned above (undo, play over), allow the player to recover from a poor choice and try again. As mentioned previously, an interesting paradox of games is that players *expect to fail* (Crawford, 2003; Rouse, 2001), but ultimately, Crawford (2003) argues, play "must be safe" (p. 31). If recovery is difficult, players are more likely to disengage (Crawford, 2003; Rouse, 2001).

Thus, an appropriate term for this component from a design perspective would be *recoverability mechanisms*. Recoverability mechanisms also include the ability to save the game, or restart. On a smaller scale they can also include things such as healing potions, extra lives, etc. Note that these can be used as rewards, but they are also often placed strategically within the game and available whenever the player reaches that point. It is *recoverability*, at least in part, that distinguishes computer games from real life.

Information devices

Information devices provide additional information beyond what is expected from the cause-effect flow of information from player-game interaction. They can be visual, aural, or tactile (such as the rumble feature in some game controllers). For example, information can be transmitted aurally through sound effects, or through communications from friendly characters in the game. Visual displays can include status bars, or instrument panels, for example. The player may have to activate the device to get the information, otherwise information devices are generally not under the control of the player; the information they deliver is controlled by the game.

It seems apparent that *embedded helps* are present in games although they are not discussed as such. In general, these helps should be non-intrusive, and non-didactic, that is; they should appear as if they arise naturally out of the interaction wherever possible. The quality of appearing natural preserves the participant's sense of accomplishment. Certainly from the perspective of players, they prefer to "figure it out on their own;" they tend to seek didactic help as a last resort (Dempsey, Haynes, Lucassen, & Casey, 2002; Heeter, Brian, & Greene, 2005; Waelder, 2006). Therefore, I submit that *embedded helps* is an appropriate descriptor for these subcomponents and constitutes a core component of computer games.

Summary of Core Components of Computer Games

The purpose of this analysis was to identify the core components of computer games. It would be expected that there would be many important subcomponents and properties that could not be discussed here. The above analysis addresses all of the potential components from the different authors although it frames all but two, self-consistent setting and meaningful challenge, as subcomponents of larger core components (see Table 5). This analysis reduces the ambiguities between authors and better organizes and illustrates the interrelationships between the proposed essential components of computer games. Therefore, I submit that the core components of computer games are

1. Meaningful challenge: An achievable goal of endogenous value that entails conflict constrained by operational rules and limited resources.
2. Self-consistent Setting: A co-constructed alternate reality defined by constituative rules, and represented thematically.
3. Player Presence: The means to make your decisions and actions manifest in the setting through the *core performance* and its observable effect in the game.
4. Embedded Helps: Resources or mechanisms within the self-consistent setting that provide a reasonable assurance of safety, and that assist, encourage, or guide the player to toward the goal.

Table 5.

Final core components compared to potential components by author

Crawford	Costikyan	Rollings & Adams	Salen & Zimmerman	Huizinga	Avedon & Sutton-Smith	Juul
			Meaningful Challenge			
	Goals				Goals	
	Endogenous Meaning					Valorization of Outcome
Inter-player Conflict	Struggle	Challenge	Conflict	Test of Prowess	Opposition	Player Effort
Rules	Rules	Rules	Operational Rules	Rules	Rules	Rules
	Resources				Equipment	
			Implicit in Meaningful Challenge			
			Quantifiable Outcome		Disequilibrial Outcome	Variable, Quantifiable Outcome
		Dramatic Tension	Uncertainty	Tension		
			Self-consistent Setting			
Focused Fantasy	Representation	Game World	Artificial Reality	Temporary World	Setting	
(Inherent Rules)			Constituative Rules			
		Storytelling	Narrative Descriptors			
			Player Presence			
Key Element		Player's Role	Core Mechanic		Procedure	
					Role	
Elegant Controls	Interactivity	User Interface	Narrow Input			
Organic Response		Presentation	Immediate Feedback			
			Embedded Helps			
			Rewards and Punishments		Pay-off	
Safety						

CHAPTER 6 —OPERATIONAL PRINCIPLES OF ENGAGEMENT

Having identified the core structural components of games, the question still remains: How do these structures work together to elicit engagement? I postulate that games are engaging because they function as *simulated adaptive systems* to create a *feedforward effect* in players. To lay the groundwork for this assertion, a brief discussion of systems is in order.

Overview of System Types and Feedforward Nature of Games

A well-known type of system is a *feedback system*. Bogart (1980) and Rosen (1985) argue that the paradigm of feedback systems is so ubiquitous that it has, until recently, obscured anticipatory systems such as *feedforward systems* and *adaptive systems*. These three types of systems and how they apply to games will be briefly discussed below.

Feedback Systems

The concept of feedback comes out of cybernetics and systems theory (Ashby, 1956; Bogart, 1980; Heylighen & Joslyn, 2001; Joensuu, 2006). A feedback system is so-called because the output of the system is "fed back" as input to the controller as shown in Figure 2 (Heylighen & Joslyn, 2001; Hubka & Eder, 1988; Macmillan, 1955; Shearer, Kulakowski, & Gardner, 1997). The most common type of feedback system works to counteract disturbances in order to maintain a desired state (Heylighen & Joslyn, 2001; Hubka & Eder, 1988; Joensuu, 2006; Shearer et al., 1997). In other words, an "error" has occurred and the systems reacts to correct the error (Macmillan, 1955; Rosen, 1985; Shearer et al., 1997).

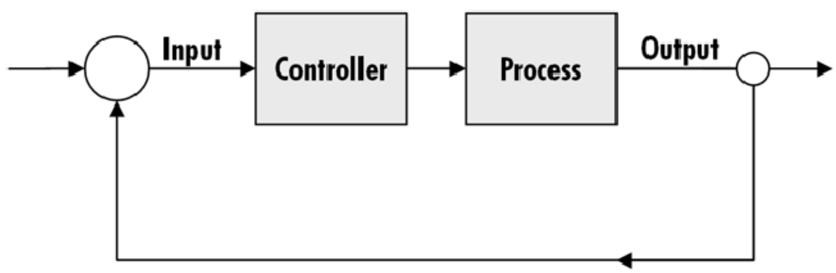

Figure 2. Diagram of a simple feedback system

A simple example of a feedback system is a thermostat and furnace. The thermostat (controller) monitors the heat (input) in the room. When the heat dips behold a threshold value (the error condition) the process is invoked (the furnace turns on) to "output" heat into the room. Similarly, the output raises the temperature of the room (input) until the upper threshold is reached, and the furnace is turned off.

Computer games are often represented as feedback systems (Heaton, 2006; Prensky, 2001; Rollings & Adams, 2003; Rouse, 2001; Salen & Zimmerman, 2004). (For an extensive discussion of feedback and games see Salen and Zimmerman (2004).) Notice the similarities between diagrams of game interactions from Salen and Zimmerman (2004) (see Figure 3), and Heaton (2006) (see Figure 4) with the above diagram of a feedback system (see Figure 2).

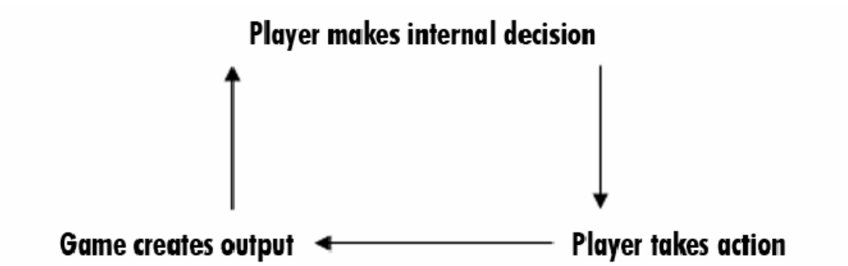

Figure 3. Diagram of "decision loop" from Salen & Zimmerman (2004)

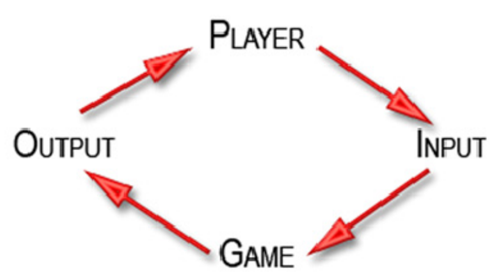

Figure 4. Circular model of gameplay from Heaton (2006)

Certainly, feedback is essential to computer games. However, the focus on feedback may have obscured the feedforward nature of computer games.

Feedforward Systems

Although the idea of feedforward existed in the early development of systems theory (Bogart, 1980; Heylighen & Joslyn, 2001), practical successes in feedback systems overshadowed the research and development of feedforward systems (Bogart, 1980; Chalam, 1987; Shearer et al., 1997). Thus, feedback is now a common term in many fields while feedforward is not so well known (Bogart, 1980). However, with recent advances in microprocessors, feedforward systems have become more practical; consequently, interest in and development of these types of systems has been increasing (Chalam, 1987; Principe, Euliano, & Lefebvre, 2000; Sandberg et al., 2001).

Simple feedforward systems anticipate future conditions and act, but do not monitor the outcome (see Figure 5) (Heylighen & Joslyn, 2001; Joensuu, 2006). An

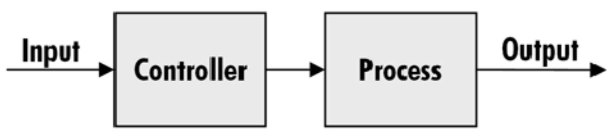

Figure 5. Diagram of a simple feedforward system (predictive)

automatic sprinkler system is one example of a feedforward system; it anticipates the need for watering the lawn at regular intervals. But its prediction may not be accurate. The classic example, of course, is when the automatic sprinkler turns on in the middle of a rainstorm. Another example of a feedforward system is noise-canceling headphones. These headphones detect the potential disturbance of noise and cancel it out before it can interfere with the hearing process (see Figure 6). In other words, it anticipates the error condition and acts to prevent it.

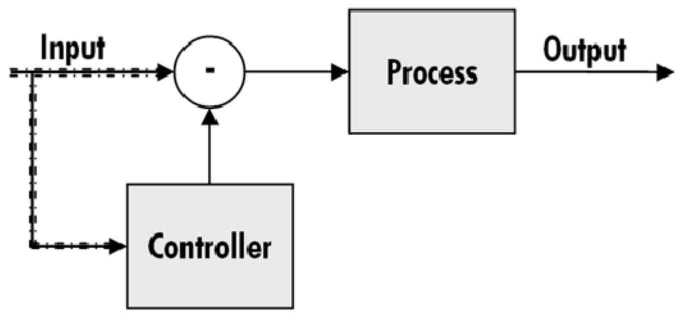

Figure 6. Diagram of a simple feedforward system (preventative)

Many computer games have elements of simple feedforward systems. The game has systems built in to anticipate the players' actions (a disturbance) and to try to prevent it. For example, in one of the games to be reviewed below, *Delta Force 3*, some enemies have been placed in the probable path the player will take to reach the objective. Following this path tends to result in the greatest number of confrontations. However, if the player takes a path that avoids confrontation, these enemies do not detect the change in the player's strategy, but will remain in place in anticipation of an encounter that may never occur. In short, the game system is designed to anticipate players' actions and to oppose their progress, but may not necessarily change its own behaviors. This feedforward nature of games may be sufficient to elicit engagement; however, it may be more accurate to say that the power of games lies in the *player's perception* that games are adaptive systems.

Adaptive Systems

There is another class of systems with feedforward characteristics that can be referred to as adaptive systems (Chalam, 1987; Holland, 1996; Principe et al., 2000; Rosen, 1985). Adaptive systems can be artificial or organic. According to Holland (1996) and Rosen (1985; 2000), all living organisms are adaptive systems. Adaptive systems can rely on feedforward mechanisms only, such as feedforward neural networks in computing (Principe et al., 2000; Sandberg et al., 2001). Yet, they can also have both feedforward and feedback components (Principe et al., 2000; Sandberg et al., 2001).

Holland (1996) refers to adaptive systems also as *agents*. In this dissertation, when talking about artificial systems or adaptive systems in general, I will refer to adaptive systems. When referring to living organisms, especially human beings, I will prefer the term *agent*.

The critical feature of this class of systems is that they "learn;" they can change their behavior based on past and present experience to make better predictions in order to achieve a desired future state or goal (Holland, 1996; Joensuu, 2006; Principe et al., 2000; Rosen, 1985; Sandberg et al., 2001). It is important to emphasize that learning occurs for the purpose of improving the anticipatory, or *feedforward* component of the system.

To summarize, feedback systems have a reactive model. They can detect an error condition and correct it, but feedback systems do not of themselves change their model—they do not learn. Simple feedforward systems are anticipatory; they act in the present based on anticipations about the future. However, their anticipatory model is also fixed; they also do not learn. Adaptive systems can have feedforward components only, or both feedback and feedforward components, but the major distinction of these systems is that they can change their own model. In other words, *they can learn*. The purpose of learning is to better anticipate future conditions. Thus, adaptive systems act in the present based on predictions about the future, but can also correct or adapt their behavior relative to the goal by learning from present and past results to refine the predictive model and its associated behaviors.

Computer games have feedback components (Crawford, 2003; Salen & Zimmerman, 2004). Further, the game is also constructed to anticipate possible future conditions or strategies; therefore, it qualifies as a simple feedforward system. Most computer games are not adaptive systems although adaptivity of NPC's is an area of game development. It is perhaps safer to say that computer games are simulated adaptive systems. Adaptivity appears to be simulated in some games by randomization methods, such as rolling dice or shuffling cards. Thus the game is never the same twice and the player must adapt to the novel circumstances, but the game itself is not adaptive.

However, the technical qualification of the game as an adaptive system may not be necessary. It may be enough that the game system requires the human player to adapt. Adaptation occurs in the face of competition (Holland, 1996; Rosen, 1985, 2000), but both systems do not have to be anticipatory to be in conflict. Heylighen and Joslyn (2001) assert that for any two interacting systems, “If the two goals are incompatible, this is a model of conflict or competition” (p. 17). Thus, if the game system hinders the player’s ability to achieve the goal, the game is in conflict with the player. It would not seem difficult, therefore, for the player to imagine, or to play *as if* the game were adaptive. According to Crawford (2003), it is sufficient that the players perceive (or pretend) that they are competing against an active adaptive system.

In the board game *Monopoly*, for example, the use of two dice makes it impossible to acquire a monopoly of properties without circling the board at lease once. With only one die, it would be possible to acquire a monopoly in two or three turns. Thus, the game’s rules make it less likely that the player will achieve the goal quickly, which heightens the conflict. The game creates a situation through randomization to which the player must adapt, without itself being an adaptive system.

Therefore, since human players are adaptive and therefore agents (Holland, 1996), the essential requirement may simply be that the game challenges players' own anticipatory, adaptive capacity within a safe, alternate reality. Because the game is designed to conflict with players' goals and to be patterned but unpredictable, the player can impute adaptivity to the game. Thus, while some games may be adaptive, it is only necessary that they *simulate* adaptivity.

This formulation of challenging players' adaptive abilities also resolves the debate about puzzles and so-called "goalless" games such as Sim-City (Costikyan, 1994, 2002; Crawford, 2003; Salen & Zimmerman, 2004). These also provide suitable, albeit different, situations to safely test adaptive abilities. Nonetheless, it would stand to reason, that the closer a game approximated an active, adaptive agent, the more intense the gameplay experience would be. Further, it also explains why games that were once engaging become boring: no further adaptation is required of the player. Viewing games in this way gives us a mechanism to understand differences in games and the different forms and levels of engagement they elicit. Therefore, I submit that the active principle that drives engagement in computer games is players' intrinsic desire to develop, test and refine their own anticipatory, adaptive abilities, or in other words, their *feedforward processes*.

Given the above postulate, the implication is that the game requires players to invest something of themselves in the game; one's own adaptive abilities are on the line. This imaginative investment of self[2] is the essential quality of entering the *magic circle* referred to by Salen and Zimmerman (2004). It is this emotional investment of oneself—*to see if I am up to the challenge*—that supplies the motivational energy that underlies the significant expenditure of time and effort (see also Crawford, 2003; Rouse, 2001) which the game then channels and shapes through its structures and actions. Thus, the game system works to continually engender anticipations of encounters that will test player's adaptive abilities. Therefore, the well-designed game creates a feedforward effect on players' imaginative investment of themselves in the game.

Operational Principles of Engagement in Computer Games

I have now identified the core structural components and an active principle to postulate an overall operational principle of engagement in computer games. I propose that the core components of *meaningful challenge*, *self-consistent setting*, *embedded helps*, and *player presence*, when well-designed, simulate (or possibly comprise) an adaptive system. This simulated adaptive system encourages player investment of self, and

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[2] This is not to be confused with the *immersive fallacy* which holds that players temporarily *become* their game world character (Salen & Zimmerman, 2004). The player is cognizant of the make-believe nature of the game, thus, the term *imaginative investment*.

consistently elicits anticipatory, adaptive actions from the player; in other words, it generates an adaptive feedforward effect. Therefore, I define the operational principle of game engagement as a safe, simulated (or actual) adaptive system that generates an adaptive feedforward effect on players' imaginative investment of themselves in the game.

While this overall operational principle is helpful, it would be more beneficial from a design perspective to better understand operational principles of each of the core design components (*self-consistent setting*, *meaningful challenge*, *embedded helps*, and *player presence*) and how they interact with players. As Vincenti (1990) notes, components and sub-components have their own operational principles that function concurrently within the system. Therefore, I will postulate an operational principle for each core component (see Table 6) and describe how it interacts with players' anticipatory, adaptive processes.

Table 6.

Core components and related operational principles

Core Design Component	Related Operational Principle
Self-consistent Setting	Thematic Signaling
Meaningful challenge	Variable Challenge
Embedded Helps	Recoverability
Player Presence	Core Performance

I propose to demonstrate that 1) the major features of the *self-consistent setting* are communicated, and engender anticipations through the operational principle of *thematic signaling*; 2) *meaningful challenge* continually elicits player engagement through the operational principle of *cycles of variable challenge*; 3) a feature of *embedded helps* encourages continued investment in the game through the operational principle of *recoverability*; and 4) *player presence* is enhanced through the operational principle of *core performance*. Each of these operational principles works in concert with the others to elicit engagement through the anticipatory adaptive processes of the agent. In the section that follows, I will first briefly elaborate characteristics of agents as adaptive systems, and then demonstrate how the game structure interacts with players as agents.

For this discussion, I will rely primarily on the writings of Holland (1996), Rosen (1985; 2000), and Kelly (1955/1963, see also Kelly, 1992). The ideas expressed by these authors are remarkably similar, yet appear to have been developed independently. Holland and Rosen argue primarily from a systems point of view, while Kelly approaches the discussion from the perspective of human psychology.

Feedforward Effect on Player as Agent

Thematic signaling

Agents take action based upon a predictive model of a given situation (Holland, 1996; Kelly, 1955/1963; Reigler, 2003; Rosen, 1985). An agent does not comprehend the entirety of a situation, but rather has an internal representation, or model that approximates the situation to a greater or lesser extent. The model is predictive and generates present actions based on anticipated goals with respect to the situation. To emphasize—a model is, of necessity, incomplete, and is also, therefore, subjective (Holland, 1996; Kelly, 1955/1963; Rosen, 1985, 2000). Thus, a model can be characterized, as Crawford (1984) characterizes a game, as a subjective subset of reality.

The term *model* does not capture the sense of subjectivity, but rather connotes a degree of objectivity. Therefore, to better capture the subjective nature of the model, I will borrow Kelly's (1955/1963) roughly synonymous term of *construct*. Kelly derives the term *construct* from construing, or the person's process of making meaning. Thus, the term *construct* also better implies the role of the human agent in creating the mental model.

According to Kelly, constructs are shaped by the experiential memories, emotions, and values through which an individual construes meaning. Thus, some aspects of a given construct will be learned and shared socially, while other associations will be personal (Kelly, 1955/1963). For example, parts of the construct of *family* will be relatively common, but certainly, each individual, even within the same family, will have different experiences and therefore a similar yet different construct of *family*.

Constructs do not exist in isolation; they are interrelated by means of similarity and contrast with other constructs (Kelly, 1955/1963). For example, any given *planet* shares essential similarities with all other *planets*. Yet the construct *planet* stands in contrast to the construct *star* for example. Further, *Earth* is part of the classification *planet* yet stands in contrast by its individual differences to all other bodies of the same classification. Thus, a construct inherently comprises what is included, what is excluded, and what is irrelevant (Kelly, 1955/1963).

According to Kelly (1955/1963), a construct is called to mind when we encounter a similar pattern or situation. Further, agents anticipate that the present situation will be substantially similar to previous situations that shaped the construct. They will, therefore, base their actions on those anticipations (Kelly, 1955/1963). (This is similar to Schank's (1998; 1999) concept of a *script.* He argues, for example, that the waitress and the patron know how to behave toward each other because they share the "restaurant script" developed by previous experiences in restaurants.)

The essential function of *thematic signaling* is to evoke a familiar construct. The means by which *thematic signaling* accomplishes its function is best described by Salen and Zimmerman (2004) as *narrative descriptors*. To reiterate, narrative descriptors represent aspects of the game world; they are not a story, but communicate a sense of story (Salen & Zimmerman, 2004). For example, the iconic pirate skull in Figure 7 functions as a narrative descriptor. It is not itself a story, yet it calls to mind the familiar stories and conventions of the pirate genre. This single image (see Figure 7) brings to mind a somewhat flexible yet finite range of related constructs regarding time, place, dress, mannerisms, values, types of conflict and other expectations associated with pirates.

Figure 7. Pirate skull (from Disney's Pirates of the Caribbean©)

The initial anticipations generated by *thematic signaling* must be appealing enough to overcome the threshold condition of suspension of disbelief. Once inside the game world, *thematic signaling* continues to reinforce or confirm these anticipations, often in the background of the participant's consciousness (Rollings & Adams, 2003). To violate the consistency of the theme is to call into question the construct that is operating in the mind of the player, and perhaps, to evoke a contradictory construct, and therefore create confusion. Thus properties such as artistic unity or harmony communicate a sense of the stability and predictability of the game world. Consequently, *thematic signaling* evokes related constructs that engender anticipations about the game world, how it operates, and the experiences that may be possible within it through narrative descriptors. Therefore, I will formulate the operational principle of *thematic signaling* as follows: *Narrative descriptors that consistently evoke the constructs of the alternate reality*.

Variable challenge

Learning to anticipate and influence the course of events is an innate goal of agents (Holland, 1996; Kelly, 1955/1963; Reigler, 2003; Rosen, 1985). The purpose of learning is to refine the agent's anticipatory construct and/or to improve performance of the actions called for by the construct. To the extent that the construct allows the agent to adequately anticipate and/or control events, the construct is confirmed, and no substantial learning appears necessary (Kelly, 1955/1963). Of course, validation—confirming that the construct still works—is also valuable. Nonetheless, when the construct is inadequate or fails, there is a natural desire to reevaluate the construct or to improve performance arises (see also "expectation failure" Schank, 2004). Thus, increasing adaptive ability, or learning, is an intrinsic drive of agents (Holland, 1996; Kelly, 1955/1963).

Games tap into this innate desire to learn (Crawford, 2003; Gee, 2003; Papert, 1998; Prensky, 2001; Rieber, 1996). In essence, the game tests the adaptive abilities of the player through the challenges it presents. Thus, challenge is central to learning in games. The challenge reveals the strengths or weaknesses of the agent's construct and the agent's execution of associated behaviors. Thus, *meaningful challenge* affirms existing ability and/or exposes the need for new learning.

Games are often held together by a long-term goal of endogenous value. Accomplishing the goal requires players to overcome multiple intermediate challenges. The long-term goal serves as a persistent object of anticipation, thereby creating a sustained feedforward effect. The long-term goal also provides justification and value to the intermediate challenges, while the intermediate challenges provide regular, near-term opportunities to affirm successful learning.

Intermediate challenges are similar to the device of dramatic tension or "plot hooks" in literature (Dickey, 2006; Huizinga, 1944/1970; Rollings & Adams, 2003); as one challenge ends another challenge arises enticing the player forward episodically. Intermediate challenges comprise iterations or cycles of *variable challenge* that lead up to the final "confrontation." Thus, games offer a stream of varying opportunities to develop and test adaptive abilities through *cycles of provocation and resolution*.

Provocation signals a challenge and an invitation to engage (Swan, 2005). The challenge calls into question players' ability or knowledge, and thus, stirs a natural desire to respond (Swan, 2005). But the challenge does not compel; always, the player has the choice to engage or disengage. If players accept voluntarily, then they engage, much like the gears of a car, in the sense of interlocking or enmeshing with the system of the game.

Once the player engages, the cycles of *variable challenge* continue to pull the player forward by presenting opportunities for continued adaptation. Adaptation may occur when the strategies and tactics of the opponent change even though the nature of the challenge is fundamentally unchanged. In basketball, for example, the challenge of scoring points remains basically the same. But each team is regularly changing players, changing offensive plays, and defensive strategies in response to strategies and tactics of the opposing team, and also in anticipation of disrupting the same opposing strategies and tactics. These ongoing responses to changing conditions create cycles of adaptation in terms of strategy and performance selection.

As skill increases, what was a challenge may become easy, and therefore boring. Computer games try to keep up with the growth in skill by increasing the difficulty of the challenge incrementally (Crawford, 2003; Rollings & Adams, 2003; Salen & Zimmerman, 2004). For example, in the arcade game *Centipede,* one way difficulty is increased as levels progress is by adding individual “bugs” that are more difficult to shoot. Consequently, the player needs greater skill in aiming and timing the shot. Thus, the necessary adaptation may be an increase in skill. In short, challenges can vary in terms of strategy and performance selection (breadth of strategies or abilities) or in terms of strategy and performance execution (depth of skill or expertise).

Each cycle of challenge has an outcome or resolution. This study will prefer the term *resolution* as it connotes both the outcome of the activity and the feeling of accomplishment and satisfaction in the player. (The possibility of failure will be addressed in the following section on *recoverability*.) The positive resolution of a challenge is innately satisfying because it affirms a successful adaptive strategy (Crawford, 2003; Kelly, 1955/1963). Further, current success engenders expectations of future success (Bandura & Locke, 2003; Hoffman, 2003). Crawford (2003) uses this analogy to refer to iterative success: "It's like eating popcorn; each piece is small but tastes so good that you readily move on to the next piece, until you suddenly realize that you have consumed a gallon of popcorn" (p. 47).

In summary, players desire to test and extend their adaptive abilities—or to put it more romantically—to "test their prowess" (Huizinga, 1944/1970). As Crawford (2003) asserts, "We measure ourselves by the challenges we face. …We therefore go through life seeking new challenges that permit us to expand our identities" (p. 37). Therefore, I will formulate the operational principle of *variable challenge* as follows: *Cycles of provocation and resolution that repeatedly invite players to test their constructs and adaptive capabilities.*

Recoverability

Learning is not univalent; it may be adaptive or maladaptive (Holland, 1996; Kelly, 1955/1963; Rosen, 1985, 2000). In other words, learning entails risk for the agent. Trying a new strategy or performance may fail. Since survival of the agent is a superordinate goal (Holland, 1996; Rosen, 1985, 2000), safety is always a primary concern although a riskier alternative may accrue advantages not available from the safest choice (Kelly, 1955/1963). Kelly (1955/1963) asserts that agents tend to make the choice they *think* will be the most advantageous. Of course, the agent's choice may or may not actually be the most advantageous.

Based on the above discussion of agents, I will define *agency* as follows: *the ability to adequately anticipate and carry out successful adaptive behaviors*. Agency in this sense goes beyond mere choice since all choices are not of equal value. As indicated above, a course of action can be adaptive or maladaptive. In an evolutionary sense, the maladaptive strategy eventually leads to the demise of the organism, and by this definition, a loss of agency. The adaptive strategy generally leads to an increase of ability to operate successfully within the world, and therefore an increase in agency. Therefore, implicit in this definition of agency is the need for knowledge, creativity, ability, evaluative judgment, and continued learning to develop better anticipatory constructs and adaptive behaviors.

At the most basic level then, an agent's expression of agency is to act based on the construct that appears to hold the promise of growth (Kelly, 1955/1963). But humans, at least, are aware that their construct is imperfect; they are aware of the downside of safety. As Zeelenberg (1999) indicates, "If you opt for the sure thing you normally do not learn whether the gamble would have been better" (p. 97). Acting on a better construct or a different construct—taking a risk—may yield more advantageous results. Furthermore, it is just as useful to know what does not work as well as what does work. It would therefore, be of considerable adaptive value to develop and test these strategies and abilities within a safe environment. This, of course, is one of the salient features of play and games (Crawford, 2003; Huizinga, 1944/1970; Papert, 1998; Rieber, 1996; Salen & Zimmerman, 2004). Thus, the ability to try out riskier strategies and behaviors in relative safety would be adaptively appealing.

The perception of safety makes the risk of learning more palatable. *Embedded helps* in computer games promote a sense of safety in a variety of ways. However, this study will focus on one element of safety that is particularly salient for computer games—

the ability to quickly recover from mistakes. Again, the interesting paradox of games is that players expect to fail (Crawford, 2003; Rouse, 2001). *Recoverability* allows the player to try again, usually at or near the point of failure. This feature lessens the impact of failure and heightens the prospect of learning. In the game context, punishments or failure simply pinpoint a weak adaptive construct. *Recoverability* provides an opportunity to develop and test changes to the construct and performances until one can be found that succeeds. Knowing that they can quickly recover encourages players to practice and experiment (Crawford, 2003). Even losing the game is safe, because losing players can always dissociate themselves from the loss in the end; they can laugh it off and walk away, because after all, "it is only a game."

Thus, risk with *recoverability* has a feedforward effect. Otherwise, as Crawford (2003) indicates, "players will resort to conservative, careful, plodding strategies—which aren't much fun" (p. 32). Thus, I will formulate the operational principle of *recoverability* as follows: *Mechanisms that allow the participant to overcome mistakes or that restore the participant to a prior status and encourage continued effort and experimentation.*

Core performance

Eventually, agents have to carry out their adaptive strategies and behaviors in the physical world. For human agents, this occurs through the use of their body. Therefore, to discuss this element of agency, the discussion must turn to the field of physiology and motor control.

Anticipatory mechanisms play an important role in motor control (Hatches, 2005; Schmidt & Lee, 2005; Seidler, Noll, & Thiers, 2004). This is especially true in sports and other activities that require fast action. Because of the inherent lag time, feedback is an insufficient explanation for skilled performance; the responses required of players occur too rapidly (Hatches, 2005; Miyamoto, Morimoto, Doya, & Kawato, 2004; Reigler, 2003; Seidler et al., 2004; Williams, 1999). Thus, athletes must anticipate the needed action mentally and physically; then in-the-moment feedback can be used to refine the actual execution of the motion (Hoffmann, Stoecker, & Kunde, 2004; Miyamoto et al., 2004; Schack, 2004; Wolpert, Ghahramani, & Flanagan, 2001). For example, Schack (2004) notes that quick-spikers in volleyball have to anticipate the opposing block and where to aim the hit while beginning to execute the spike.

It is important to note that in the initial learning of the skill, *feedback* is prominent (Seidler et al., 2004). The purpose of continued learning and practice, however, appears to be to build the anticipatory mechanisms necessary for skilled performance (Hoffmann et al., 2004; Hohm, Felzer, & Marenbach, 1996; Seidler et al., 2004; Wolpert et al., 2001). In this way, skilled performance becomes relatively automatic (Bugmann, 2001; Schmidt & Lee, 2005; Williams, 1999).

The ability to make motor performance automatic is explained according to one developing theory in that motor control is composed of *movement primitives*: or modular units of learned anticipatory movements (Mussa-Ivaldi & Solla, 2004; Schaal, 2003, 2006; Schaal, Peters, Nakanishi, & Ijspeert, 2004; Sosnik, Hauptmann, Karni, & Flash, 2004). Small movement primitives can be combined into large movement primitives such as “grasping a cup,” or a “tennis serve” (Schaal, 1999, 2003; Sosnik et al., 2004). This seems to have its corollary cognitively in Kelly’s (1955/1963) concept of a construct. In other words, the essential idea behind these cognitive and motor control units is that they can be aggregated as a single entity rather than a collection of discrete memory bits, signals and/or actions. Consequently, when recalled and executed as a unit, they are not as memory- or as process-intensive (Schaal, 1999, 2003; Sosnik et al., 2004).

This relates to the *core performance* in that it appears that the performance required of players, both cognitive and physical, often needs to be learned and executed as an aggregate anticipatory unit. Further that performance of these strategy-action units needs to become relatively automatic. This automaticity is particularly necessary in twitch-speed games. Yet, even with slower strategy games, the psychological distance between thought and action should remain small for engagement to remain high.

When players have reached a reasonable level of mastery of the *core performance*, they can then perceive themselves as simply "acting in the world" and not consciously manipulating controls (Crawford, 2003; Rollings & Adams, 2003). (In this one can also see the need for elegant controls (Crawford, 1984).) Further, automaticity allows conscious activity to be geared toward the necessary in-the-moment adaptations of strategy and performance. I would argue that this perception of acting relatively automatically is fundamental to immersion in the game.

Thus to facilitate immersive engagement, the *core performance* should remain a single, or a small set of integrated performances (Crawford, 1984; Salen & Zimmerman, 2004). That does not necessarily mean simple. For example, the game of basketball has a *core performance* set consisting of dribbling, passing, shooting, rebounding, and defending. However, within this set is an almost infinite variety and complexity of action. Keeping the *core performance* as a small integrated set of modular behaviors allows players to learn them as anticipatory units, to explore possible variations of the skills, and again, frees up cognitive resources for other purposes (Bugmann, 2001; Schmidt & Lee, 2005; Williams, 1999).

Under this assumption that the *core performance* is an adaptive behavior, then learning and improving the behavior itself (regardless of the goal state) is a satisfying accomplishment. By being able to focus on a small set of integrated performances, even small improvements are more observable and feed the player's desire to continue improving. Small accomplishments may become lost or meaningless when too much is required.

In summary, the *core performance* is anticipatory and improvements in the *core performance* are intrinsically satisfying. Through the *core performance*, players have the means to demonstrate their adaptive ability; in other words, to express their agency. Consequently, I will formulate the operational principle of *core performance* as follows: *A focused, relatively automatic set of anticipatory, adaptive behaviors required to successfully meet a challenge*.

In summary, I have shown how each of the operational principles associated with the core components (*self-consistent setting*, *meaningful challenge*, *embedded helps*, and *player presence*) interacts with the player's agentive desires to elicit engagement (see Table 7). The *self-consistent setting*, through *thematic signaling*, evokes a construct, or anticipatory model of rules, relationships, and actions. The *variable challenge*, through cycles of provocation and resolution, elicits the desire to test one's capabilities and

Table 7.

Summary of core components, operational principles, and influence on player

Core Design Component	Related Operational Principle	Influence on Player Agency
Self-consistent Setting	Thematic Signaling	Evokes a familiar construct
Meaningful challenge	Variable Challenge	Tests adaptive ability
Embedded Helps	Recoverability	Encourages experimentation
Player Presence	Core Performance	Facilitates immersive action

provides a stream of small successes to encourage the player forward. Even in the face of failure, *recoverability* allows the player to focus on fixing the performance at the point of failure, and encourages the player to keep trying. Finally, a well-designed *core performance* allows the player to forget about the mechanics and to become actively immersed in the game.

As noted above the concept of feedback has been a dominant paradigm in systems theory, in games, and in education. But feedback is insufficient to explain the anticipatory, adaptive behavior of agents (Bogart, 1980; Holland, 1996; Kelly, 1955/1963; Rosen, 1985; Schaal, 2006; Seidler et al., 2004; Zeelenberg, 1999). As has been demonstrated above, the additional concept of *feedforward* provides a richer explanation of the phenomenon of player engagement in games. Therefore, I propose that these core components through their operational principles interact with players' innate anticipatory, adaptive mechanisms to create a *feedforward* effect that engenders and sustains engagement in games.

CHAPTER 7 — EVIDENCE OF OPERATIONAL PRINCIPLES OF ENGAGEMENT IN COMPUTER GAMES

Analysis of Operational Principles in Selected Computer Games

The next step is to demonstrate that the operational principles defined correspond to the design of actual computer games. It should be noted that the goal of reverse engineering is to find and describe what should already be present; the purpose is not to generate predictive theory and attempt to falsify the prediction. Therefore, if the job of reverse engineering is complete one would expect to find each design element in each case although the form and emphasis of the operational principle may vary.

To illustrate the operational principles, I will examine how *thematic signaling*, *variable challenge*, *recoverability*, and *core performance* are implemented in *Delta Force 3* (DF3), *Mario Kart: Double Dash*, *7th Guest*, and *Tetris*. These games were selected in part on the assumption that they are engaging as demonstrated by their popularity. For this discussion, I will focus on the single player features of the games. The objective of this chapter is not to give an exhaustive review of these games, but to provide evidence that these operational principles are used in these games. I begin with *thematic signaling* since this is the initial experience before the challenge begins.

Thematic Signaling

To review, the purpose of *thematic signaling* is to evoke in the player the foundational construct of the game world and therefore to generate anticipations about the kind of experience that awaits. During gameplay, t*hematic signaling* continues to reinforce the construct and to create anticipations by foreshadowing events that await. When *thematic signaling* is done well it does not intrude, but everything seems to fit naturally. Further, elements that might stretch the construct are rationalized in the theme. When thematic signaling is done well it is almost subliminal; when it is done poorly, it calls attention to itself rather than receding into the background. At its worst it sends mixed signals and hinders engagement. With the possible exception of one version of *Tetris*, the games selected represent good examples of *thematic signaling*.

Delta Force 3. In DF3 the player is a member of a secret unit of the U.S. military known as Delta Force. Thus, the essential constructs are of secrecy and soldiery. *Thematic signaling* begins as soon as you launch the program. The colors are shadowy and go from brown to black with red lines and red and white lettering. In the background, a world map implies that your assignments could take you anywhere (see Figure 8). The music starts low with a long synthesizer sound and intermittent percussion which escalates to a heart-thumping, hard rock rhythm. The music and graphics signal a world of stealth and intrigue punctuated with adrenaline-pumping action.

Figure 8. Main menu from Delta Force 3

Even the cursor is no longer the standard arrow, but is now a circle with crosshairs in the middle. As you move your mouse over interactive boxes, you hear a metallic clinking. When you make a selection, you hear what sounds like either a cartridge being loaded into the chamber of a rifle, or the safety being released. In either case, a weapon is being readied and you are being primed for action. Everything signals that you have entered the world of Delta Force.

When you select a mission, a female voice gives you a briefing in a matter-of-fact tone of voice (see Figure 9). Already values are being communicated implicitly: you are a

Figure 9. Mission briefing screen from Delta Force 3

soldier; this is a job. Further, for example, terrorists (bad guys) have taken hostages (innocent victims) in Egypt and are making demands. The Egyptian government (good guys, but civilians) wants Delta Force to rescue the hostages without public incident (they *need you* to help them do the right thing: protect innocent civilians without negotiating with terrorists); therefore, you are free to “eliminate any hostiles” to secure the hostages. Through this means, the game uses *thematic signaling* to communicate the social and political values of the game world and the important role you have to play in it.

The game also uses iconic symbols to help "transport" you to that area of the world. For example, in the first mission in Egypt, pyramids are prominent in the background, and in short order, you come upon the Sphinx (see Figure 10). There are a

Figure 10. First mission in Egypt from Delta Force 3

few more missions in Egypt, and, although the symbols of Egypt are gone, other narrative descriptors such as the desertscape and palm trees continue to reinforce your location in Egypt (see Figure 11). A similar patter occurs with missions in Mexico where the first mission features a Mayan temple and ruins, and in Japan which prominently features Japanese pagodas. These narrative descriptors quickly and almost unconsciously communicate country and culture.

Figure 11. Second mission in Egypt from Delta Force 3

DF3 also uses *thematic signaling* to explain the visual and aural interface and informational elements of the game. As a Delta Force soldier you are equipped with the latest body armor and weaponry. In addition, you have a state-of-the-art head's up display (HUD). Your HUD can receive satellite information showing enemy locations and GPS coordinates of your own position. Position information is displayed in the black circle at the bottom left of the screen (see Figure 11). The green icon is yourself, a blue icon is an ally (friendly), and the red icons are enemies. It also shows you the status of your weapons and your current body position (standing, crouched, or prone) (see Figures 10 and 11). And it does not take explaining to know that the green crosshairs in the middle are how you aim your weapon. You also carry a two-way radio through which other Delta Force members and your game character provide information to you in the guise of communicating between themselves. Thus, *thematic signaling* is used to explain virtually all of the information you receive; what you see on screen and hear "over the radio" are just part of the equipment you carry as a member of Delta Force.

There are several ways that DF3 thematically foreshadows upcoming events. Two will be highlighted here. First, the HUD displays enemy locations in the GPS display. Thus, you are cued that challenges still await and you can decide whether to use stealth to avoid the confrontation or to engage the enemy. Second, when your presence is detected by an enemy, they will begin shouting. Through the stereo headphones this actually gives you information as to approximately how close and in what direction the enemy is located. In addition, it lets you know that they are alert. Thus, you have to be ready when you confront them because alert enemies in DF3 react to you quicker and aim better. Again, through these seemingly natural means information is communicated and anticipations are engendered.

Notice that the game world is rendered realistically (see Figures 10 and 11). Given the absence of any indicators to the contrary, the player's assumption is that the normal laws of physics apply. These are just a few of the ways that DF3 communicates rules, goals, and game states through *thematic signaling*. Therefore, the operational principle of *thematic signaling* is present in DF3.

Mario Kart: Double Dash. The foundational constructs in *Mario Kart* are racing and cartoon violence. When you launch *Mario Kart: Double Dash*, you see animated clips of cartoonish characters racing in cartoonish cars (see Figure 12). They are throwing strange items at each other, and bumping into each other. Colors are generally bright, primary colors. The music is jaunty and upbeat. The menus are also consistently cartoonish. You are being prepared for quite a different reality.

Figure 12. Opening screen of Mario Kart: Double Dash

To begin a race you have to select two characters (a driver and a rider) and a vehicle. For anyone who has played one of the many popular Mario games, the characters are familiar. Some of the vehicles look like cartoon versions of realistic cars. There are others, however, that are imaginative and funny such as the baby buggies or the steam engine. This use of *thematic signaling* communicates that different rules apply to these races (if baby buggies can keep up with “souped up” cars, then the rules are different).

When you are at the starting line, the starter is a bird-like character that flies in on a cloud holding the starting lights on a pole. The lights are similar enough to lights for drag racing that you know what they are, and you know to wait until the lights cycle through to green. Again, through *thematic signaling* the game gives you familiar signs that this is a race, but also that this is still a cartoon world where quirky things can happen.

Power-ups are also part of the convention of computer games (Rollings & Adams, 2003). Many Mario games have power-ups and *Mario Kart* is no different. These power-ups are placed in different locations around the track. As you drive through them and you get randomized items that the rider can throw at other racers to knock them around, or that the rider can use to give yourself special temporary powers. The power-ups are consistent with the cartoon theme. For example, a banana peel causes cars to slip and spin around; a bomb blows any car within its blast radius up into the sky (see Figure 13). These power-ups change the game from just a race with cartoon characters to a real cartoon race with the wacky and unpredictable quality of cartoon mayhem.

In summary, irrationality is allowed in cartoons. It is no surprise then that in a cartoon game, a race car can be blown sky high, land intact, and continue the race; or that

Figure 13. Screenshot of Mario Kart character ready to throw an item

it can fall off the track and be fished out of the depths by a bird-like character on a cloud and be placed back on the track. The cartoon representation opens up these possibilities. The *thematic signaling* of the cartoon genre in *Mario Kart* cues you to expect the unexpected. Therefore, the operational principle of *thematic signaling* is present in *Mario Kart*.

7th Guest. The constructs of *7th Guest* are of mystery and the supernatural. There is a fairly extensive backstory to *7th Guest* that is told through video clips when you first launch the game. With eerie music in the background, a book opens up. The illustrations on its pages come to life (see Figure 14) and voice-over narration reveals the story is of one, Stauff— who, through various events, becomes an evil, demented yet wealthy toymaker. Until suddenly, the children, clutching their beloved Stauff toys, become sick

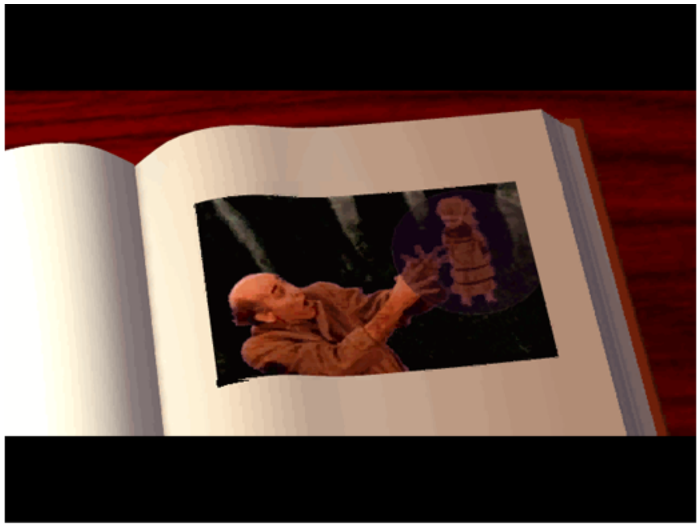

Figure 14. Illustrations come to life in 7th Guest.

and die. Stauff has one final vision—a strange mansion filled with strange puzzles isolated on a craggy precipice. His final act is to build the mansion.

The scene pulls back from the book and you find that you are inside Stauff's darkened mansion. You are moved into the foyer. There you see six ghostly guests appear and enter the mansion (see Figure 15). Stauff has invited them here but you do not know why. The scene ends, you turn, and a hushed voice—*your voice*—says, "I remember . . . . nothing. Already, at least two mysteries are implied but unstated: What are the guests doing here? and, What are *you* doing here?

Through the thematic signaling of music, story, and imagery, you are primed for a supernatural mystery. Supernatural events have already taken place so you are not surprised when the guests appear and disappear and you hear disembodied voices.

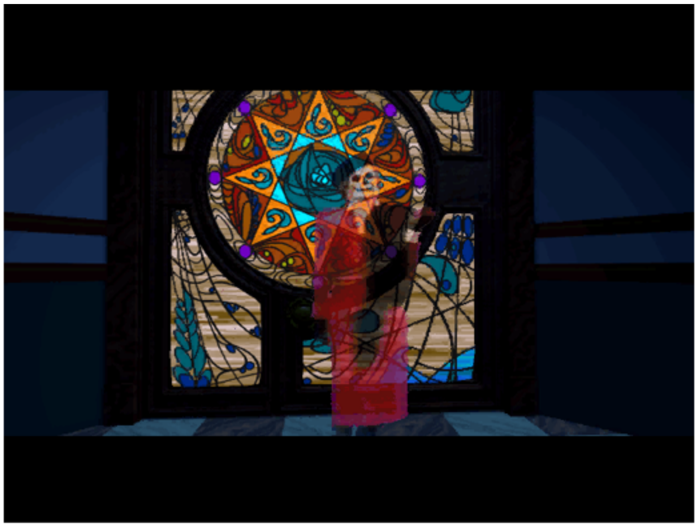

Figure 15. One of the six ghostly guests arrives at Stauff's mansion in 7th Guest.

Further, you have been provided a thematic rationale for the presence of the strange puzzles throughout the house (Stauff is a demented toymaker). This thematic rationale gives coherence to the game; otherwise it is just a collection of puzzles.

Thematic signaling continues after the backstory ends. You are still in the gloomy foyer facing a large curving staircase (see Figure 16). The lighting, the décor, the staircase, the marble floor thematically signal the wealth of an earlier era. The gloomy lighting and the ghosts evoke the assumption that the mansion is vacant; you are the only *living* being present. As with DF3, the visual representation of the computer controls is consistent with the illusion of this setting. The mouse pointer is in the form of a bony white skeleton hand. When the area is not interactive, the pointer finger is straight up

Figure 16. The foyer of Stauff's mansion in 7th Guest

and the hand wags from side to side as if to say, “No, you can’t go here” (see Figure 16). As you move the pointer to an “open” door that the motion changes. The pointer finger now moves forward and back, pointing ahead—“you can go this way” (see Figure 17).

Figure 17. Navigable door signaled thematically by skeleton hand pointing.

You click the right mouse button and you move forward. The means of navigation has been communicated quickly, effectively and thematically.

Once inside a room, the presence of a puzzle is indicated by the cursor changing to a skull with eyeballs and a half-exposed, throbbing brain (see Figure 18). Another

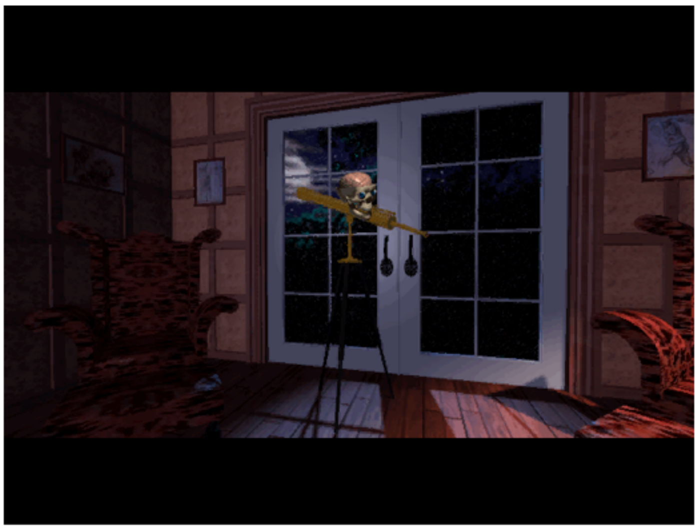

Figure 18. Throbbing brain signals a puzzle inside the telescope.

mouse click and the puzzle is presented. Although these are really just abstract puzzles and could be presented any number of ways, they too are represented thematically. For example, the cake puzzle has skulls and headstones as decorations (see Figure 19).

Thematic foreshadowing is also used in 7th Guest. The doors to the rooms are not all open; you unlock them as you progress through the game. Occasionally, a ghostly

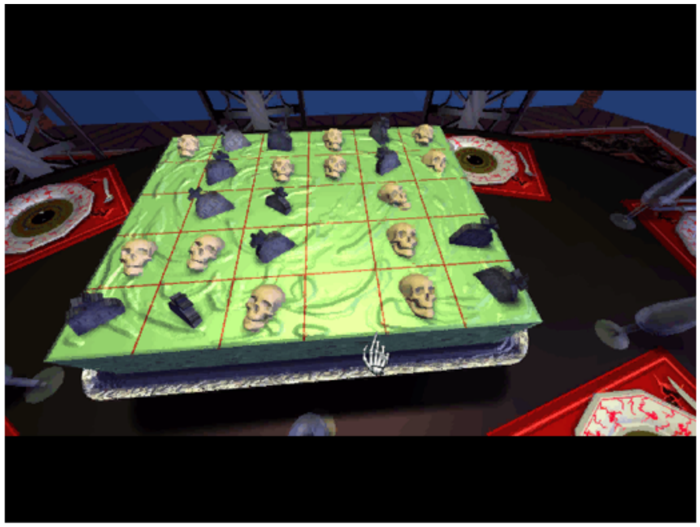

Figure 19. Thematically represented puzzle in 7th Guest

woman will appear in the hall beckoning you, signaling that there are open doors in that direction (see Figure 20). In addition, a few cut scenes are enacted in the hall; characters disappearing through the door also signal that the door is now open.

Figure 20. A possible path signaled thematically by the beckoning apparition.

Thematic signaling is the strength of 7th Guest; it is the mood and the mystery that keep you playing the game (see Crawford, 2003). You watch ghosts reenact events. The puzzles are rationalized and represented thematically. In these ways and others, 7th Guest employs thematic signaling to evoke and affirm constructs of mystery and the supernatural.

Tetris. The game of *Tetris* has an interesting history (see www.*Tetris*.com). Suffice it to say that the international copyright and trademark rights were disputed for a number of years. Yet, it became very popular and many derivative versions were created. For the purposes of analyzing *thematic signaling* I will examine three different versions.

Tetris is the simplest and most abstract game in the review. According to one version, *Tetris* taps into the human desire to create order out of chaos (Blue Planet Software, 2008). Thus, the construct evoked is order and disorder. Many versions of *Tetris* are very sparse in their interface signaling the abstract nature of the game (see Figure 21). The game is played in a rectangle. As the game begins, the empty space is in a state of order. The pieces are composed of four perfect squares. Very simply, the geometric nature signals orderliness. Yet because of the different possible shapes, these same orderly geometric pieces create disorder. As soon as the first piece drops in order is disrupted. Through these very basic means the conflict of order and chaos are *thematically signaled*.

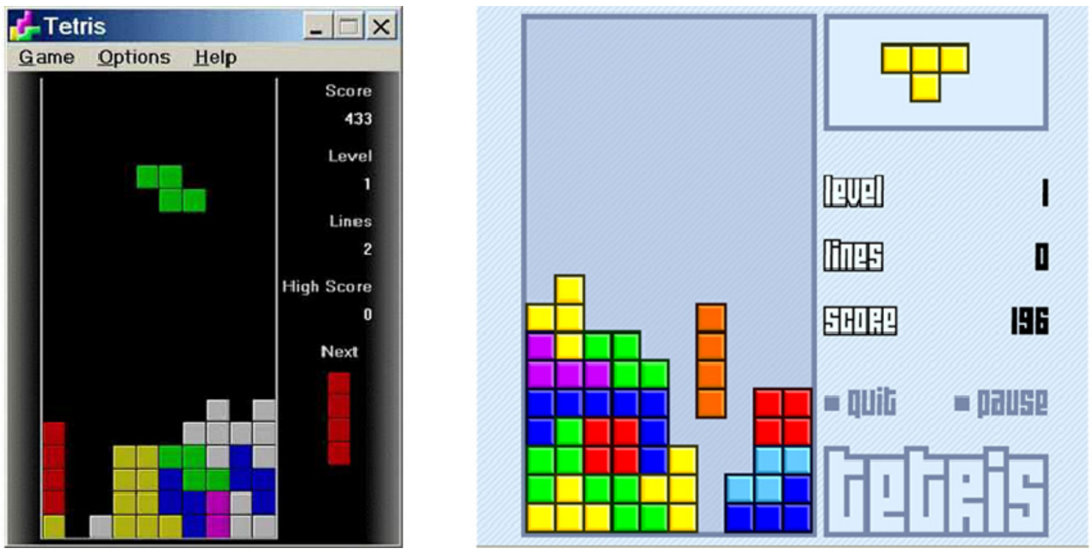

Figure 21. Screenshots of different versions of *Tetris*

Contrast the two versions of *Tetris* in Figure 21 with the version in Figure 22. In my opinion, the version in Figure 22 is a less than exemplary case of thematic signaling. The graphics begin to call attention to themselves and in reality they are not necessary for the game. In fairness, this is a more recent version of Tetris. The makers may feel that they have to distinguish their version from the many other versions. The background graphics are a quick way to create this distinction. Yet, even though this version dresses up their interface, it still employs *thematic signaling*. The theme of the graphics is abstract and mechanistic.

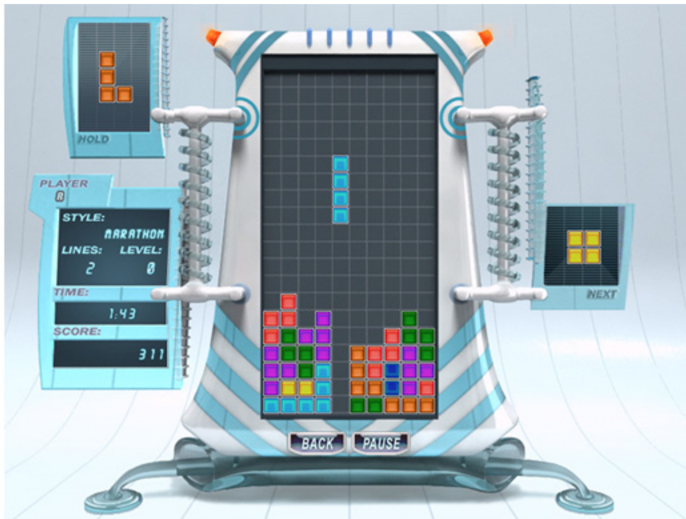

Figure 22. Screenshot of a third version of *Tetris*

This newer version also has background music which has a "techno" flavor that is consistent with the mechanistic theme. Sound effects consist of clicks, whirs, and dings—again, fairly mechanistic. *Tetris* is like a machine: the pieces just keep dropping down, faster and faster. Therefore, although this may not be the best example, *thematic signaling* is still employed.

The theme of *Tetris* is simple and relatively abstract compared to the other games reviewed. If anything, the third theme is slightly overdone; some elements do little to enhance the game experience. As history has shown, *Tetris* is a compelling game without the glossy backgrounds. Nonetheless, *thematic signaling* is present in all versions and it is consistent.

When *thematic signaling* is done right, it feels so natural that it is almost invisible. Perhaps this is why, when it is done poorly, it is difficult to pin down what is wrong. If there is a tendency, it seems there is a tendency to overdo (Crawford, 2003; Rollings & Adams, 2003). *Thematic signaling* need not be sophisticated to work.

Each of the above games uses *thematic signaling* to communicate game world values, how the game world operates, and other game information. Much of this communication is implicit. Further, *thematic signaling* helps generate anticipations about the game experience. Therefore, I submit that there is evidence that *thematic signaling* is an operational principle of engagement in computer games.

Variable Challenge

To review, *variable challenge* presents a stream of tests to players' adaptive abilities through cycles of provocation and resolution. The challenges can vary in terms of breadth of applicable circumstances and/or in terms of increasing the depth of expertise required.

Delta Force 3. The campaign in DF3 has a long term goal of eliminating a terrorist organization. This goal provides a thread of story that loosely ties missions together. Missions are constructed so that they are largely self-contained. Each mission has at least one objective; sometimes there are three or four. These, of course, also represent various challenges to be met. But, the basic unit of challenge that recurs again and again, the *variable challenge*, is the skirmish with enemy combatants.

These skirmishes are not continuous but they do occur regularly along the path toward the mission objective. Between each skirmish there is a chance to "catch your breath." It is most common to encounter two enemies at a time, but some skirmishes include up to four of five enemies. There does not seem to be any sequential pattern of increased difficulty of the encounters either within a mission or from mission to mission. The basic challenge of winning the firefight stays essentially the same; it is the variety of situations that keep changing.

Some enemies are at a distance; some are up close. Sometimes enemies are unaware of you presence and you have time to set up the shot. Other times, enemies are shooting at you but you do not know where they are. Some enemies are stationary while others are moving. Some times you are out in the open with little cover (see Figure 23), and other times you are in buildings or tunnels with sharp corners and closed doors that may conceal enemies (see Figure 24). Thus, you are never quite sure when you will encounter the next threat, what the threat will be, and you must be ready to adapt to the situation at all times. Skirmishes with the enemy constitute cycles of provocation and resolution. Therefore, DF3 uses variable challenge to keep players engaged.

Figure 23. Open field skirmish from Delta Force 3.

Figure 24. Skirmish inside a building from Delta Force 3.

Mario Kart: Double Dash. *Mario Kart* uses *variable challenge* through a variety of race courses and through increased difficulty levels. First they have four "Grand Prix" which contain four race courses each. Each Grand Prix "cup" increases in difficulty and potential hazards. In addition, you can also select the "engine class" of 50 cc, 100 cc, or 150 cc (see Table 8). With each class of car the speed increases; therefore, maneuvering is more difficult; you have to be a better driver. Further, the NPC's you are playing against are better and are more aggressive. They bump into you more and it seems that there are more active power-up items being thrown. However, as you increase in class size within a Grand Prix the racetracks stay substantially the same. (In a few cases, possible shortcuts are added or hazards are changed slightly.) Thus within a Grand Prix, the race courses repeat but the difficulty increases with each engine class.

Table 8.

Variable difficulty in Mario Kart by Grand Prix and engine size

	Grand Prix*			
	Mushroom Cup	Flower Cup	Star Cup	Crown Cup
Engine size**	50 cc	50 cc	50 cc	50 cc
	100 cc	100 cc	100 cc	100 cc
	150 cc	150 cc	150 cc	150 cc

* Increased difficulty left to right. ** Increased difficulty top to bottom.

Within races, the twists and turns of the race course provide their own *cycles of provocation and resolution*. Each race course is a challenge to your driving abilities. You have to mentally map the course and learn to anticipate and execute the turns. At the same time, another *variable challenge* is present. Your fellow racers are throwing items at you or leaving them in the racetrack in your way. Avoiding the hazards is a successful and satisfying momentary resolution. However, if you get hit, that of course, is a direct provocation. You want to throw some items of your own. I have to admit that it is fun in this cartoon race-world to throw a turtle shell and see the car in front of you roll over as you race by.

In my experience, players' abilities and the NPC's abilities are fairly evenly matched at the 150 cc level. In addition, the items you are throwing at each other add enough variation and instability that it is always a challenging race. At this level the challenge because the throwing items creates some unpredictability; thus, there is still the need to adapt on the fly. Therefore, *Mario Kart* employs *variable challenge* through randomization factors (collecting and throwing items), different race courses, and through different difficulty levels.

7th Guest. The ostensible *variable challenge* in *7th Guest* is to solve puzzles. Each room contains a puzzle. Each is different but at the same time, they are all logic puzzles. The puzzles are of roughly equal difficulty. Further, there is no set sequence in which you encounter the puzzles; this would seem to argue against any purposeful escalation of difficulty. Thus, there is *variable challenge* in the variation of the puzzles.

Of course, each puzzle and its solution is a *cycle of provocation and resolution*. In addition, the voice of Stauff enhances this provocation by taunting you when you begin a puzzle. With the cake puzzle, for example, Stauff taunts, "Become a gravedigger have we?! …You must be a glutton…for punishment." His taunting can also occur during the puzzle if you make a bad choice, or if you have to start over again. As you solve a puzzle the sense of resolution is also enhanced through voice-over. Your reward is not only the satisfaction of seeing the solution, but also of hearing Stauff get angry that you solved his puzzle. This device makes it a little more personal—the puzzle is not just an abstract hurdle to get to the next part—you are "beating Stauff at his own game."

But it is also true that the puzzle that matters most is the mystery of the seventh guest. It is this mystery, more than the prospect of another challenging puzzle, which keeps you moving forward. In this respect *7th Guest* also uses *cycles of provocation and resolution*. When you solve a puzzle, you unlock a cut scene that gives you another segment of the story. But even as the cut scene resolves some questions, it provokes more questions than it answers. Thus, you want to continue in order to get the next piece of the story and see if you can put it all together.

Crawford (Crawford, 2003) probably has it right: the puzzles are good, but 7th Guest is more a story than it is a game. However, they do work well enough together tokeep you playing the game. More to the point, 7th Guest employs the operational principle of *variable challenge*.

Tetris. The challenge in *Tetris* is not to win the game, but to survive as long as possible by ordering the pieces. In order to survive, you have to clear lines of blocks. In order to clear lines, you have to fit pieces together so that there are no remaining gaps. Each piece dropping down is a potential threat. If you place it well and there are no gaps, there is a momentary resolution. But the next piece is already dropping down. If you are forced to place the piece such that it may leave a gap that may not allow you to clear a line, there is no resolution. You are waiting for a piece that you can use to repair the gap. If you are forced to cover up the gap so that you cannot clear that line, then you are trying to clear the lines to expose the gap, so that you can fill it in. And still the next piece is dropping down. Each piece is a potential challenge or a potential resolution; there may not be a suitable place for the piece to fit, or the piece may be the one you are waiting for to clear lines.

Again, making pieces fit neatly is momentarily satisfying. Clearing lines also brings resolution. The maximum number of lines you can clear at one time is four (called a *tetris*) (see Figure 22 above). Managing the flow of pieces to create a nice solid block then positioning and dropping the straight "I" piece—that is a victory. But still the next piece is dropping down.

Of course, *Tetris* also increases the challenge incrementally. As you clear more lines and move up levels, the speed with which the pieces drop increases. You have less time to plan and to maneuver the pieces into place. Yet still the next piece is dropping down. In this way, the *variable challenge* of *Tetris* is unrelenting. It is perhaps this feature that makes *Tetris* so addicting. Therefore, *Tetris* employs *variable challenge* through the different situations each piece creates as well as is through the incremental increase in speed.

All of the above games use *cycles of provocation and resolution* to generate *variable challenges* that keep you moving toward the goal of the game. Enemies are strategically placed in DF3 to cause a series of skirmishes until you accomplish the mission objective(s). In *Mario Kart*, each race has its own challenges, and you have multiple races to win a Grand Prix. With each level of engine class, you repeat the same race courses but with increased difficulty. In *7th Guest*, you solve each puzzle to find out more about the mystery. Each cut scene both reveals and conceals; thus, maintaining the mystery to keep you moving forward. Each piece in *Tetris* creates its own challenge which you can resolve by placing it well and/or clearing lines. The increase in speed requires quicker thinking and positioning to clear lines. These games present a stream of challenges that vary in breadth of circumstance and some that increase the level of required performance.

Therefore, there is evidence that *variable challenge* is an operational principle of engagement in games.

Recoverability

To review, *recoverability* provides mechanisms to overcome mistakes or to restore the player to a prior status in the game. This allows players to develop and test changes to the construct and performances until one can be found that succeeds. *Recoverability* encourages continued effort and experimentation.

Delta Force 3. A more subtle form of *recoverability* in DF3 is that you can sustain more damage than your enemies due the light body armor you are equipped with. Additionally you can choose as an option to wear the Kevlar vest that will further prevent some injury. (An injury is signaled by a quick flash of red.) On the other hand, shooting anything on a terrorist, even an exposed knee or a foot, will "kill" the enemy. Thus, if you are a little slow on the trigger and get injured, you may still win the skirmish because of the extra protection.

Recoverability also includes the ability to quickly restart a mission as well as saving a mission in progress in DF3. If you are killed before completing the mission you can quickly restart by pressing the space bar. This avoids the normal startup time when you first load the mission.

However, some of the missions take a long time to complete. If you are fifteen or twenty minutes into a game, restarting from the beginning is not a palatable option. Fortunately, DF3 further provides *recoverability* by allowing you to save a mission at any time. There are enough breaks in the action that saving is not overly distracting. If you then die, you can load the saved mission and continue from the last saved point.

Of course, you have to remember to save regularly. While learning the game, it was a greater priority for me to save. As I got better and died less often, I began to save less often. This could be particularly frustrating if you were near the end of the mission and died without saving. But it was also true that knowing that I had just saved the game made it much more comfortable to be a little more daring and take on the next risk. There are games that have more seamless save game features (Crawford, 2003; Rouse, 2001); nonetheless, the operational principle of *recoverability* is present in DF3.

Mario Kart: Double Dash. The races only last three to four minutes in *Mario Kart*, therefore, saving a race does not make sense. You can, however, easily restart. But the primary mechanism of *recoverability* is made part of the game through the power-up items. If you are falling behind, you can use the items to boost your speed or to disrupt racers in front of you. If you observe carefully, you can see that when you are behind, you seem to get more active items that speed you up, or that you can throw directly at other cars. When you are in the lead you seem to get more passive items such as banana peels (these just sit on the road and drivers can avoid them). Thus, if you are behind in the race, you can throw items at the racers ahead of you to knock them over and slow them down, or use items that increase your speed, thus, giving you a chance to catch up and pass them. Consequently, there is always a chance to recover until just before crossing the finish line. Therefore, the operational principle of *recoverability* is present in *Mario Kart*.

7th Guest. You can save a game and you can also restart the entire game in *7th Guest*. However, unlike DF3, saving is really only necessary when you are exiting the game; you do not get killed so the game does not end until you decide to leave. Therefore, the restart and save game feature are not the primary recoverability mechanisms.

Recoverability is accomplished mainly through the ability to reset the puzzle infinitely. If you make an unrecoverable mistake in a puzzle, the game automatically resets for you (with an appropriate taunt from Stauff). If you "get lost" in your own strategy and cannot find your way back, you can manually reset the puzzle. Further, if you are still stuck on a puzzle you can return to the book in the study; its pages will contain a clue (see Figure 25). You can visit the book twice for a clue. If you still cannot solve the puzzle and want to move on, you can return to the book a third time. Now the puzzle is "solved" for you. The penalty is that you do not see the cut scene for that puzzle. But other effects such as unlocking other rooms occur; therefore you can continue in the

Figure 25. The book in the study provides hints to solve the puzzle.

game and not be interminably stuck at that puzzle. Thus, you are encouraged to try solving the puzzle; however, you can *recover* from a puzzle you cannot solve and continue the game. In these ways, the operational principle of *recoverability* is present in *7th Guest*.

Tetris. *Recoverability* is quite simple in *Tetris* and is also built into the game play itself. In *Tetris*, the fatal flaw is to build up incomplete lines. Sometimes, you have no choice but to cover up an incomplete row. *Recoverability* in *Tetris* consists in the fact that you can clear the lines above to re-expose the incomplete line. You then have another chance to complete and clear the line. Like *Mario Kart*, *recoverability* is built into the challenge rather than existing as a separate function. Thus, the operational principle of *recoverability* is also present in *Tetris*.

Each of the above games has different ways that you that you can recover from a mistake in the game. DF3 relies primarily on the save game feature. *Mario Kart* provides power-ups that can help you or hinder your opponents. *7th Guest* lets you reset a puzzle at any time, and ultimately, will solve the puzzle for you if you are really stuck. In *Tetris*, by clearing lines, you can expose previous mistakes and clear them. *Recoverability* in these games encourages continued effort and experimentation; therefore, the presence of the above mechanisms in these games provides evidence that *recoverability* is an operational principle of engagement in games.

Core Performance

To review, the *core performance* is a single, or a limited set of integrated anticipatory, adaptive behaviors required to meet the challenge. The *core performance* is like a good research question: it limits the number of behavioral variables so that successes and failures are more accurately attributable to an observable behavior, thereby allowing focused improvements. By keeping the *core performance* elegant, performance can become relatively automatic.

Delta Force 3. DF3 is the most complex of the games reviewed in terms of the available controls. Yet, you do not need most of them to play and win the game. They are helpful, they can enhance the game, but they are not necessary. What is vital is to use the arrow keys to move, and moving the mouse to steer and clicking the right mouse button to shoot (see Figure 26). Thus, the *core performance* consists of moving, aiming and shooting. These are the performances that need to become fairly automatic. The physical controls to accomplish these functions are few and simple as well. In my experience, the performance of moving and shooting becomes automatic—your thoughts are focused on your strategies and actions in the game world. Therefore, I submit that DF3 has implemented the operational principle of *core performance*.

Figure 26. Essential keyboard and mouse controls for Delta Force 3

Mario Kart: Double Dash. The *core performance* in *Mario Kart* is driving and throwing items. To drive, you press and hold the "A" button on the game controller to accelerate (see Figure 27). You steer with your left hand using the joystick. To throw an item you can aim the throw forward or backward with the joystick and press either the "X" or the "Y" button. There is, however, one critical maneuver in driving you must

Figure 27. Controls for Mario Kart: Double Dash

master to be competitive—that maneuver is the *power slide*. The power slide is really a controlled skid that allows you to take curves, even hairpin turns, without losing speed. In fact, it is the most effective way to control the vehicle. You execute the power slide by initiating a turn with the joystick, then pressing and holding either the right or left button. You can continue to adjust the power slide with the joystick. To end the power slide you simply release the left or right button.

To win, you have to throw items, but that action is fairly easy to learn. Steering on the straighter sections of the course with the joystick is also reasonably easy. Being able to control the power slide is the best way to take turns and avoid obstacles. To win in the 100 cc and 150 cc levels, the power slide is essential. The power slide is integrated into the driving. As you can see in Figure 27, *Mario Kart* demonstrates elegant controls that allow you to focus on a *core performance*. Therefore, the operational principle of *core performance* is present in *Mario Kart*.

7th Guest. Navigationally, the *core performance* for *7th Guest* is quite simple. You can accomplish everything by pointing the animated cursor at the interactive object and clicking the right mouse button. The real *core performance* for *7th Guest*, however, is solving puzzles using a little bit of logic and a healthy dose of trial and error. In this case, the *core performance* has little to do with mastering controls as is necessary in DF3, *Mario Kart*, and *Tetris*; nonetheless, there is a *core performance* for *7th Guest*. Although it is primarily mental, the operational principle of *core performance* is present in *7th Guest*.

Tetris. The *core performance* for *Tetris* is rotating pieces, positioning them laterally, and optionally accelerating their drop using the computer keyboard. You use the up arrow key to rotate the piece in 90° increments. You use the right and left arrow keys to move the piece laterally. You use the down arrow key for a "soft drop" (the piece speeds up), or the space bar for a "hard drop" (the piece drops into place immediately). As you can see in Figure 28, the controls are simple and straightforward. In order to succeed at higher levels of the game, you have to rotate and position the piece quickly and accurately, therefore, it is necessary to learn operate the controls relatively automatically. Again in my experience, the actions are simple enough that you can become automatic at them. Therefore, *Tetris* also employs the operational principles of *core performance*.

Figure 28. Keyboard controls for Classic Tetris.

In summary, each of the above games also implements the operational principle of *core performance*. DF3 focuses on moving and shooting. Similarly, *Mario Kart* requires driving and throwing items with an emphasis on the power slide. The core performance in *7th Guest* is contained in the reasoning and puzzle-solving strategies of the player. *Tetris* only requires rotating, positioning and dropping pieces as its *core performance*. The *core performances* are relatively straightforward and allow you to master the mechanics so that you can immerse yourself in the game. Therefore, I submit that these games provide evidence that *core performance* is an operational principle of engagement in computer games.

Conclusion of Analysis of Computer Games

The purpose of this section was to provide evidence that the operational principles of *thematic signaling*, *variable challenge*, *recoverability*, and *core performance* are present in actual games. The four games chosen represent different game types. *Tetris* and *7th Guest* are not prototypical games. Therefore, finding the operational principles in these games would allow for a reasonable inference that these principles are generally present in computer games. Each of the games demonstrated the instantiation of each of the operational principles. Therefore, the criterion of *correspondence* of the reverse engineering effort to actual artifacts has been met. Consequently, I conclude that there is evidence that these operational principles are present in computer games and that they contribute to the ability of these games to elicit engagement.

General Operational Principles of Engaging Experiences

The first reverse engineering question of this dissertation was formulated as follows: By examining the design of computer games as an exemplar, can I, as the reverse engineer, identify and describe operational principles for the design of engaging experiences? Through the process of reverse engineering, core components of computer games were identified and described. With only one revision, changing *player presence* to *agentive means*, the core components are sufficiently general. The change to *agentive means* is discussed below.

Agentive Means. Participants express their agency through the *core performance*. The *core performance* is manifest through some physical representation. Therefore, the means include any resources, raw materials, equipment, space, or information that the participant needs to practice and refine the *core performance*. For computer games some form of physical controls are necessary. This may or may not be the case for experiences in general. The *means* may simply be the venue for a physical performance or oral presentation, for example. In short, *agentive means* are all things necessary for the participant to execute the *core performance*. A*gentive means* is therefore a more general core component of engaging experiences.

Therefore, I will generalize the set of core components as follows:

1) Meaningful Challenge: An achievable goal of endogenous value that entails conflict constrained by operational rules and limited resources.
2) Self-consistent Setting: A co-constructed imaginative or physical subset of reality defined by constituative rules, and represented thematically.

3) Agentive Means: The means to develop and demonstrate sound judgment and effective action through the core performance and its observable effect.

4) Embedded Helps: Resources or mechanisms within the designed experience that provide a reasonable assurance of safety, and that assist, encourage, or guide the development of adaptive abilities.

In addition, the interactions of these components with players' anticipatory adaptive abilities were described. From this I postulated four operational principles related to the above core components. These operational principles remain unchanged and are,

1) Variable Challenge: Cycles of provocation and resolution that repeatedly invite players to develop and test their adaptive capabilities.

2) Thematic Signaling: Narrative descriptors that consistently evoke the constructs of the alternate reality.

3) Core Performance: A focused, relatively automatic set of anticipatory, adaptive abilities required to successfully meet the challenge.

4) Recoverability: Mechanisms that allow the participant to overcome mistakes or that restore the participant to a prior status and encourage continued effort and experimentation.

Consequently, this study has defined a general set of core design components of engaging experiences and their associated operational principles. These are summarized in Table 9.

Table 9.

Generalized core design components and associated operational principles

Core Design Component	Associated Operational Principle
Meaningful Challenge An achievable goal of endogenous value that entails conflict constrained by operational rules and limited resources.	Variable Challenge Cycles of provocation and resolution that repeatedly invite participants to develop and test their adaptive capabilities.
Self-consistent Setting A co-constructed imaginative or physical subset of reality defined by constituative rules, and represented thematically.	Thematic Signaling Narrative descriptors that consistently evoke the constructs of the setting.
Agentive Means The means to develop and demonstrate sound judgment and effective action through the core performance and its observable effect.	Core Performance A focused, relatively automatic set of anticipatory, adaptive abilities required to successfully meet the challenge
Embedded Helps Resources or mechanisms within the designed experience that provide a reasonable assurance of safety, and that assist, encourage, or guide the development of adaptive abilities.	Recoverability Mechanisms that allow the participant to overcome mistakes or that restore the participant to a prior status and encourage continued effort and experimentation.

At this point, core components and operational principles of engagement have been postulated and their presence in computer games has been demonstrated. Consequently, it is possible to conclude that the requirements for the first reverse engineering question (Can operational principles for the design of engaging experiences be identified and described?) have been met. The question that remains is to provide evidence that these operational principles can be applied to the design of instruction.

CHAPTER 8 — EVIDENCE OF OPERATIONAL PRINCIPLES OF ENGAGEMENT IN INSTRUCTIONAL CASES

In this chapter, I will identify and describe the presence of the above postulated operational principles in two cases of designed instruction. This analysis will provide the evidence to answer the second reverse engineering question referring to the application of the operational principles to the design of engaging instruction. To reiterate, the operational principles this study seeks to describe in designed instruction are

1) Variable Challenge: Cycles of provocation and resolution that repeatedly invite participants to develop and test their adaptive capabilities.
2) Thematic Signaling: Narrative descriptors that consistently evoke the constructs of the setting.
3) Core Performance: A focused, relatively automatic set of anticipatory, adaptive abilities required to successfully meet the challenge.
4) Recoverability: Mechanisms that allow the participant to overcome mistakes or that restore the participant to a prior status and encourage continued effort and experimentation.

Analysis of Operational Principles in Designed Instruction

The first instructional case is a chemistry laboratory simulation called *Virtual ChemLab: Inorganic Qualitative Analysis* (Virtual ChemLab). The second case is the design of a full-length classroom-delivered course, *Biology 100: General Biology* (Bio 100).

Given that I participated in both of these cases as an instructional designer I can approach the discussion more from the standpoint of design. One of the purposes of this dissertation is to inform the design of instruction. These cases provide an opportunity to also demonstrate how these principles were applied, even if intuitively, during the process of design.

Virtual ChemLab: Inorganic Qualitative Analysis

Inorganic qualitative analysis in chemistry focuses on the chemical behavior of ions in solution. An understanding of the chemical properties of different ions would allow you to separate and properly identify unknown ions in solution. The design team (initially myself, a subject-matter expert, and a graphic artist) identified what we considered to be two weaknesses of existing laboratory methods. One was the lock-step procedural, or "cookbook" approach to chemistry experiments. The second was our feeling was that other real activities (such as determining the amount of, and measuring, a chemical to add to the solution, stirring, pouring, centrifuging, etc.) were time-consuming and produced anxiety about process rather than interest in the chemistry (Woodfield et al., 2005; Woodfield et al., 2004). We felt that these two factors distracted from the purpose of developing learners' ability to think analytically and to understand what was happening chemically. Therefore, we chose to emphasize analytical thinking skills.

Core Performance. The emphasis on analytical thinking skills constitutes a *core performance*: the ability that we would require of learners over and over again. At the time, we were not aware of the concept of *core performance*; it was an intuitive decision on our part. Other simulations that were reviewed during the design phase employed step-by-step procedures, and often required the participant to work out and specify the amounts of chemicals to add. In our review, these were unnecessary for a computer simulation and detracted from the focus of thinking analytically.

The *core performance* of analytical thinking became our organizing principle: anything that might get in the way of the thinking process of the learner we modified or eliminated. Similar to *7th Guest*, the *core performance* in Virtual ChemLab is primarily mental. Controls were implemented through standard computer keyboard and mouse functions; therefore, there were no additional motor control skills to learn.

To focus on analytical thinking, we designed the simulation to automatically handle most of the mechanics. Centrifuging would occur in an instant. A simple mouse click would add the right amount of a chemical; would stir the solution; or measure the pH; and so on. Learners could, therefore, concentrate on the *core performance* of analyzing what was occurring chemically in the test tube. Therefore, *core performance* is an operational principle present in Virtual ChemLab.

Variable Challenge. The *meaningful challenge* in Virtual ChemLab is to devise a method, or *scheme*, to isolate and identify an unknown ion or ions in a solution (unknown). (Interestingly, the scheme is a predictive model.) This challenge can vary both in breadth and in difficulty. The simulation has 26 ions that can be present in solution. An unknown can contain none, one, or any combination of ions including all 26. Thus there are 26 possible unknowns containing a single ion, and an almost infinite number of possible combinations. The difficulty of creating a scheme for one unknown would be comparable, but would vary depending on the ion in solution. Schemes for combinations of ions, of course, would also vary in difficulty according to the complexity of the combination.

By way of analogy, Virtual ChemLab is most like a puzzle game. You have to figure out the solution to the puzzle. The initial provocation is the unknown; the unknown is a puzzle. The actions you take on the unknown either confirm your expectations or present another puzzle. Thus, the *cycles of provocation and resolution* come about through your actions. You perform an action—for example, add a chemical to the unknown solution—and the simulation displays the result. If you can explain to yourself what happened and why—if this carries you one step closer to identifying the unknown, you experience some resolution. If you cannot explain it, it provokes the question: *What did just happen and why?* You then have to opportunity to experiment with other actions to solve each stage of the puzzle, each of which may constitute its own provocation or resolution. Therefore, I submit the operational principle of *variable challenge* is found in Virtual ChemLab.

Thematic Signaling. As a design team, we also felt that the simulation needed to be engaging. Therefore, we also purposefully chose to mimic some of the conventions of computer games. Specifically, we modeled our screen layout after *Doom*, a popular, and trend-setting 3-D, "first-person shooter" computer game (see Figure 29) and further, we tried to represent interactive elements as "natural" to the environment. Moreover, we also wanted learners to take the simulation seriously. We also felt that the realistic, 3-D rendering of a laboratory environment would signal a greater level of realism (see Figure 30).

Figure 29. Screenshot of interface from Doom.

Figure 30. Screenshot of laboratory view of Virtual ChemLab.

Again, we were not consciously aware of the concept of *thematic signaling*; however, we employed this principle intuitively. We wanted the environment to be quickly recognizable as a chemistry laboratory (see Figure 30). Chemistry labs are not colorful; therefore, the colors are muted. The periodic table of elements was placed on the wall as an iconic identifier. (As a note, it was also made functional and therefore could be classified as an embedded help.) The workbench and the red waste container are typical of what would be found in a laboratory, and so on. To further enhance the realism, we also included over 2,500 photographs of actual test tubes and over 220 videos of real flame tests. The simulated test tube would show approximate results, and the actual results would be shown by the photograph or video in the larger box at the bottom left (see Figure 30).

Again, we also wanted the navigational elements to feel as "natural" as possible. As in a real laboratory, you go to the stockroom window to pick your solutions and unknowns. Clicking on the red lab book on the workbench would launch an electronic lab book where you could take notes, and where you would report your results. If you need help in a real laboratory, you ring the bell at the stockroom window; thus, clicking on the bell calls up the help features of the simulation (see Figure 31). To exit the simulation, you click on the door in the background. I submit that these examples are narrative descriptors that call up familiar constructs in learners. Therefore, *thematic signaling* is an operational principle found in Virtual ChemLab.

Recoverability. There are a variety of recoverability mechanisms in Virtual ChemLab. First, you can create identical copies of any test tube up to the number of slots

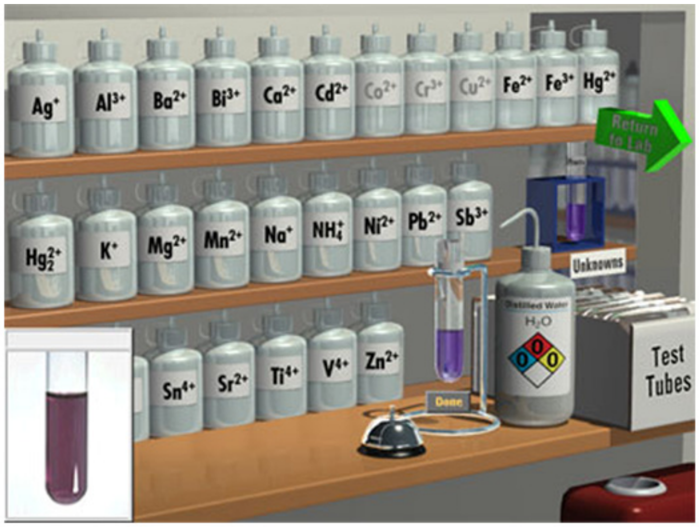

Figure 31. Screenshot of stockroom view in Virtual ChemLab.

in the blue racks at the back of the workbench (see Figure 31). Thus, if you completely mess up the solution you are working with, you can drag it to the waste container and quickly retrieve a copy. This also means that you can save "states" by copying the solution at any stage of experimentation. We briefly considered an "undo" feature that would let you backtrack steps, but felt that feature would run counter to our focus on careful analytical thinking. Further, if you were careful, kept notes, and saved copies as you went, you essentially had created your own "undo" mechanism.

Perhaps the most important *recoverability* mechanism is the ability to experiment with "practice unknowns" (Woodfield et al., 2004). The simulation allows the instructor to create an unknown solution as a class assignment that will be scored. Of course, you would like to feel confident that you can correctly identify the assigned unknown and thereby receive a high score. Through the simulation, you can test your scheme by creating practice unknowns based on the same parameters as the assigned unknown. There is no limit to the number of practice unknowns you can create. They work just like assigned unknowns; you report your results and receive immediate feedback. Although for purposes of grading, you eventually have to submit the assigned unknown, you can fail without penalty, as often as you wish, to learn how to get it right beforehand with practice unknowns. Therefore, I submit that these examples indicate that the operational principle of *recoverability* is instantiated in Virtual ChemLab.

Evidence of Engagement. For the purposes of this dissertation it is not essential to establish that Virtual ChemLab is engaging. Nonetheless, such evidence exists. In addition, a brief discussion of this evidence would build confidence that the principles asserted in this dissertation are worthy of consideration.

Evaluations of Virtual ChemLab focused primarily on educational outcomes. However, evidence was also collected that supports the conclusion that Virtual ChemLab is sufficiently engaging. A study of 35 high school students in Advanced Placement Chemistry indicated the students enjoyed using the simulation independent of performance on assignments (Swan, 2001). Another study involving the use of Virtual ChemLab in a freshman-level university chemistry course collected 1,400 surveys with open-ended comments, and conducted 26 think-aloud protocols and an unspecified number of computer laboratory observations and interviews.

Evaluators found that "over 75% of students reported that they liked Virtual ChemLab" (Moore, 2002, p. 1). The survey contained three items related to how students liked the simulation. On the question of whether Virtual ChemLab was easy to use, the average rating was 5.84 (7 point Likert scale). When asked if they liked the appearance and layout of the simulation, the rating was 6.2. When students were asked if they were satisfied with their use of Virtual ChemLab, the average rating was 5.94 (see Table 10).

Table 10.
Ratings of items on students' attitude toward Virtual ChemLab

	Ease of Use	Visual Appeal	Satisfaction
Rating*	5.84	6.2	5.94

* 7 point scale

Further, evaluators reported that it was common to receive comments that the program was "fun" (Woodfield et al., 2004). One student, for example, is quoted as saying, "In general, I really don't like chemistry all that much, especially the lab part because it's messy and time consuming, but I actually had fun using ChemLab, and that really surprised me" (p. 1676). Evaluators further reported,

> All students, no matter how long they've been in college, believe that ChemLab helps them become more confident in being a chemist ($p<0.0001$). Freshmen believed that ChemLab helped them become a more confident chemist than did sophomores, juniors or seniors—sophomores, juniors and seniors also thought ChemLab helped, but just not as much as the freshmen. (Moore, 2002, p. 1)

From this I infer that students found their experience worth their time and effort; and therefore, that their experience with Virtual ChemLab was sufficiently engaging. While more research could be done to establish the engagingness of Virtual ChemLab, there is sufficient evidence for the purposes of this dissertation to support the assertion that the simulation is engaging.

It should be noted that Salen and Zimmerman (2004) indicate that all games are simulations, but that all simulations are not games. Indeed, Aldrich (2004) argues that simulation designers should study computer games. The essential difference is that a simulation places priority on modeling a central aspect of reality; a game does not have to adhere to reality (Crawford, 2003; Salen & Zimmerman, 2004). Thus, although Virtual ChemLab may in some respects be game-like, it fits the category of educational simulation.

To summarize, all four operational principles—*core performance*, *variable challenge*, *thematic signaling* and *recoverability*—derived from the four core components of *agentive* *means*, *meaningful challenge*, *self-consistent setting*, and *embedded helps* respectively were instantiated in Virtual ChemLab. Further, evidence was provided that Virtual ChemLab is engaging. Therefore, I submit that there is evidence that operational principles of engagement can be applied to the design of instructional materials.

Biology 100: General Biology

Bio 100 is a General Education requirement at Brigham Young University. Consequently, a majority of students take the course because it is required, rather than from their own desire. A consistent concern of the Bio 100 instructor has been that genuine engagement by students with the subject and the course has remained low. A further concern was that the course emphasized lower-level cognitive skills such as memorization. In addition, the instructor felt that students entered and left the course with little observable change in their attitudes toward biology (Dye, 2007).

The instructor indicated that she and other instructors had attempted to introduce "active learning" into the course, but that these had "backfired." My assessment was that they were trying to move in the right direction, but these activities were "add-ons." The course as a whole still retained its traditional lecture-test emphasis; therefore, these activities did not represent a pedagogical shift. To use a pharmaceutical analogy, they wanted a dose of medicine to cure the symptoms without following the complete regimen.

My analysis confirmed some of the comments the instructors had received from students, therefore the instructor agreed that it was time to try redesigning the entire course. Given that this was a new approach, the instructor requested and received permission from the department to open an experimental section of the course. Students would be notified of this status prior to enrolling. It is interesting in retrospect that with this additional sense of *safety*, we felt more encouraged to test the limits of what we could do in the course. This was particularly true of the instructor.

By this time, I had developed ideas about presenting a challenge within a consistent "world" as well as the foundations of the principle of *recoverability*. More fully developed concepts of safety, *embedded helps*, *core performance*, and *thematic signaling* were not yet explicit; these, again were designed more intuitively.

Variable Challenge. It turned out in this case that *meaningful challenge* became the organizing principle to guide the design of this course. We approached the design with the question: *What challenges should a general education course in biology help a student face after they have left the university?* The conclusion we came to was that the challenges students would face as citizens in the community would probably come from political, economic and ethical issues involving evidence and arguments from the biological sciences about which they would need to make informed decisions. Consequently, the challenge we chose was for students to research and defend in writing and orally a position on a current issue involving biology.

We discussed a variety of alternative approaches but decided to focus on a single issue for the whole class to be followed throughout the semester. At the time, a proposed alternative to the theory of evolution called, *intelligent design*, was a prominent issue. Since this issue addressed the central theory of biology, it was felt that this topic might provide a good vehicle both to learn about biology and to address a controversial political issue. Therefore, the challenge we proposed to present to students was to research and defend a position on the question: *Should intelligent design be taught in public schools as a scientific alternative to the theory of evolution?*

This ambitious challenge would create *variable challenge* in a variety of ways. Challenges of comprehension included understanding the basis of scientific argumentation; understanding the theory of evolution as espoused by supporters; and understanding the proposed alternative of intelligent design as espoused by supporters. Challenges of analytical thinking would include correctly identifying the component parts of argumentation in a variety of written and oral communications. Challenges of evaluation would include evaluating the strengths and weaknesses of the evidence and arguments of these same communications, as well as evaluating the strengths and weaknesses of their own assumptions, evidence and arguments. From these pieces they would also have to evaluate the collective strengths and weaknesses of a given position. Challenges of creativity would occur in constructing their own arguments and in anticipating possible questions and counterarguments. It is safe to say that Bio 100 would present *variable challenge.* Therefore, the operational principle of *variable challenge* was present in Bio 100.

Core Performance. It might seem from the foregoing that defining a *core performance* would be difficult at best. However, if the *core performance* can be integrative, it need not be simple. Even for computer games, a desirable quality is "easy to learn, hard to master" (Crawford, 2003; Salen & Zimmerman, 2004).

Although we did not have a formal concept of *core performance*, we were asking ourselves the right question: *What is the essential nature of what we are asking students to do?* From conversations and readings we felt that the ideals and attributes of *sound reasoning* ("Aims of a BYU Education," 2004; Paul & Elder, 2001) were consistent with the ideals of science. Thus, we defined what we can now call our *core performance* as demonstrating sound scientific reasoning.

We defined sound scientific reasoning as consisting of intellectual skills and intellectual character and created a condensed list of the skills and attributes (adapted from "Aims of a BYU Education," 2004; Anderson & Krathwohl, 2001; Bloom, Krathwohl, & Masia, 1956; Paul & Elder, 2001) as follows:

Intellectual Skills

- Analyze
  - Able to distinguish the component parts of a concept, argument, model, theory, work, etc.
- Synthesize
  - Able to reconstruct component pieces into a working whole.
  - Able to apply abstract principles to concrete situations.
- Evaluate
  - Able to assign appropriate evidentiary, explanatory, aesthetic, moral and/or ethical value to a concept, argument, model, theory, work, etc.
  - Able to discern the properties, relationships, and values that are essential or important from those that are unessential or unimportant.
  - Able to distinguish sound reasoning from sophistry.

    - Create
        - Able to generate novel solutions, interpretations, relationships and works.
    - Communicate
        - Able to effectively articulate and/or advocate intellectual truths, theories, values, etc.

Intellectual Character

- Intellectual Humility
    - Acknowledging of the limitations of one's own, and humankind's, knowledge, experience, and/or intellectual ability.
    - The willingness to learn new, or expand existing knowledge, experience, and/or intellectual ability despite intellectual discomfort.
- Intellectual Empathy
    - Able to comprehend and appreciate another's concept, position, model, theory, etc. without necessarily agreeing with, or accepting it.

- Intellectual Integrity
  - Accepting the burden to seek, select, develop and apply one's own knowledge, beliefs, intellectual skills, and character according to high ethical and intellectual standards.
- Intellectual Patience
  - Being willing to hold in abeyance a final resolution to a problem or issue, or to accept provisionally a conclusion or position pending additional information or insight.
- Intellectual Charity
  - Accepting the ethical burden to assist others in their intellectual development and to apply intellectual knowledge, skill, and effort for the benefit of humankind.

It should be noted that we were under no pretensions that these skills and traits would be acquired and mastered in our short course. We did feel that it would be beneficial, however, to enunciate the ideal. It turns out that this ideal provided what we can now call the *endogenous value* of the challenge; students in general felt that these skills and traits were worthwhile to pursue and practice (Dye, 2007). In summary, *sound scientific reasoning* is an integrated performance even though it is not simple and may be difficult to master. Therefore, *core performance* is an operational principle present in the redesign of Bio 100.

Thematic Signaling. Understanding that games often provide a situated challenge, we did want to place our challenge within a scenario, especially a scenario that students might see as possibly happening to them. Therefore, we told students that they were preparing their papers and oral presentations for a "school board." The school board would be able to ask questions and challenge arguments. Therefore, they could not just find sources to support their own position; they would have to anticipate and understand possible disagreements with their position. All students would present before the instructor, teaching assistants, and the class as a "mock school board." The top three groups would present before another "mock school board" composed of faculty from different disciplines (therefore implying a range of opinions) and would receive additional points for this presentation.

Like many early text-based, role-playing games (referred to as *multi-user dungeons* or MUD's), this theme was largely represented verbally. Throughout the course we regularly referred to the school board or board members, and prompted students to think about their own experiences in public school biology classes. These narrative descriptors appeared sufficient to evoke the construct of presenting before a group of officials as many students wore suits and dresses for their presentations although no instructions were given about dress. For their final three presentations, however, we scheduled a small auditorium, had the “school board members” sit in the front row, and thus, staged a mock school board meeting. Although the theme relied heavily on student imagination, nonetheless, I submit that the operational principle of *thematic signaling* was also present in Bio 100.

Recoverability. It should be mentioned first that the controversial nature of the challenge required some additional assurance of safety. Consequently, there was repeated assurance that the papers and presentations would not be judged on the basis of agreement with the instructor’s opinion, but rather on how well they demonstrated sound scientific reasoning. Throughout the course the instructor conscientiously avoided trying to infuse her opinion in the discussion. I believe this effort further encouraged students to take the risk of thinking and speaking for themselves.

Recoverability was built into the course by providing opportunities to receive feedback and resubmit assignments and by weighting their course grade more toward their final performance. Intermediate assignments had enough points given that students would have to keep up and take the assignments seriously. Nonetheless, their final grade would depend heavily on the final papers and presentations. In other words, they could recover from mistakes made throughout the semester by demonstrating improvement at the end. In addition, all papers, intermediate and final, would be graded and given feedback. If students wanted to improve, they had the opportunity to revise and resubmit the paper. Prior to their final presentations, appointments were set up with the instructor and teaching assistants and student teams to give them a "dry run" and provide formative feedback on their position and presentation.

Implementation of *recoverability* in this course depended more on personnel to grade resubmissions and provide feedback. This logistical concern limited the scope of *recoverability* opportunities that we could offer. The unlimited practice and feedback available in Virtual ChemLab, for example, was not practical in this context. Nonetheless, opportunities to improve were provided for students with no penalty for the previous performance. Consequently, I submit that the operational principle of *recoverability* was present in the redesigned Bio 100.

Evidence of Engagement. Bio 100 was initially piloted with a group of 20 self-selected students. The following semester 50 students took the redesigned Bio 100 using normal enrollment procedures. We collected data from the institutional student rating survey administered for all courses at Brigham Young University. We compared the pilot sections for each semester to all sections of Bio 100 on three of the items of the student rating survey: Overall Course, Active Student Involvement, and Intellectual Skills Developed. On all three items, the pilot sections' ratings were above the ratings for all courses (see Table 11). It is of particular interest to this discussion to note the item on Active Student Involvement remained high.

Table 11.

*Comparison of BYU student ratings data for Biology 100**

	First Semester		Second Semester	
	Pilot	All	Pilot	All
Overall Course	6.7	4.8	5.9	5.3
Active Student Involvement	6.9	6.2	7.1	6.2
Intellectual Skills Developed	7.9	5.4	6.9	5.8

* 8 point scale

In addition, an independent evaluator interviewed 12 randomly-selected students from the second semester. The independent evaluator reported, "All the students interviewed responded positively to the course. Almost every student reported having greater interest in biology-related issues and being more willing to be involved in the work of the course" (Dye, 2007, p. 28). On the issue of willingness to put in the effort required by the course, the evaluator noted,

> All twelve students indicated the time they spent in learning for this class was worth it. They found the information interesting and felt they were really learning. They did not feel they were occupied with busy work and they thought the skills they were developing were valuable. (Dye, 2007, p. 13)

Although these findings are formative in nature, I submit that they provide evidence that the redesigned Bio 100 is engaging.

To summarize, all four operational principles—*core performance*, *variable challenge*, *thematic signaling* and *recoverability*—derived from the four core components of *agentive means*, *meaningful challenge*, *self-consistent setting*, and *embedded helps* respectively were instantiated in the redesigned Bio 100. Further, evidence was provided that Bio 100 was engaging for students. Therefore, I submit that there is evidence that operational principles of engagement can be applied to the design of classroom instruction.

Conclusion

The second reverse engineering question was stated as follows: *Can we provide evidence that these operational principles apply to the design of engaging instruction?* To answer this question, I examined two cases of designed instruction: Virtual ChemLab, a chemistry laboratory computer simulation, and Bio 100, a classroom-based general education course. The postulated operational principles of *core performance*, *variable challenge*, *thematic signaling* and *recoverability* were identified in these cases and described. In addition, evidence was presented that these cases were engaging for students. Therefore, I conclude that there is evidence that these operational principles derived from computer games can be applied to the design of engaging instruction.

CHAPTER 9 — THE TENTATIVE DESIGN THEORY OF CHALLENGE-DRIVEN INSTRUCTIONAL DESIGN

The final step according to Reigeluth and Frick (1999) is to formulate the tentative theory. The theory is termed tentative because it has not been subjected to repeated experimentation (Reigeluth & Frick, 1999). In this chapter, I will propose a tentative design theory entitled Challenge-driven Instructional Design. To develop this theory I will 1) describe the basic assumptions of the theory and their implications for instruction; 2) describe the design theory and propose a *design process by priority* that acknowledges the iterative nature of design; and 3) discuss some of the important implications of the theory for implementation in instruction.

Foundational Assumptions of Challenge-driven Instructional Design

The foundational assumptions of Challenge-driven Instructional Design can be characterized as the expansion of agency, the centrality of the simulated challenge, and endogenous and exogenous value. These are discussed below.

Expansion of Agency

The assumption upon which this theory rests is that the purpose of learning is to expand the agency of the learner. One of the unexpected findings of this study was the consistent connection of game components with the player as agent. As I progressed through the study I developed a deeper, richer view of agency. The Merriam-Webster Online Dictionary defines the word *agent* as, "1: one that acts or exerts power, 2 a: something that produces or is capable of producing an effect" ("Merriam-Webster Online Dictionary," 2007).

This definition covers both inorganic agents and organic (living) agents; therefore, it is of necessity value free. The inorganic agent *acts* according to the physical laws that govern it. The living agent, however, has some degree of choice (Holland, 1996; Kelly, 1955/1963; Rosen, 1985). The ability to act; the ability to choose are certainly elements of agency. Nonetheless, there are choices and actions that are trivial. The simple notion of choice implies selection from relatively equal options. For example, whether you choose a Whopper or a Big Mac is reasonably equivalent; it is a matter of taste, or perhaps, convenience. Further, it is relatively easy to recover from this choice (as an individual choice). But these are not the choices that matter. Again, not all choices are equivalent. Agency, especially in human terms, includes but goes beyond choice and action.

For the living organism as agent, a course of action can have life or death consequences; one choice is not as good as another. Therefore, from the most basic level of survival of the living organism, a course of action has, or does not have, survival value. Of course, the living agent would prefer not just to survive, but to thrive. Expanding one's agentive capabilities would open up further opportunities to flourish. As a simple example, the person who knows a foreign language is now able to function appropriately in a variety of new environments. Therefore, the exercise of agency is inherently value-laden.

Thus, from the perspective of agents as living adaptive systems, agency can be defined as *the ability to adequately anticipate and carry out successful adaptive behaviors*. Implicit in this definition is the ability to appropriately recognize the situation and anticipate the probable chain of events; the ability to select or plan an appropriate course of action; and the ability to effectively carry out the course of action. In short, agency includes sound judgment and effective action. In Bio 100, for example, you have to exercise sound judgment in your evaluation of arguments from both sides of the issue; you must also demonstrate your judgment through oral and written communication.

For the organism whose critical environmental variable is light and dark, the element of choice may not be large. For other agents—especially for human agents, there is an infinite variety of environments and situations in which they may find themselves. Particularly then for human agents, expanding one's agency (the range of situations one can anticipate, and the range of actions one can perform) would be an imperative. Thus, the choices and actions of interest are the choices and actions that matter to the life of the agent both in terms of surviving and thriving. In this respect, good games provide opportunities for *choices and actions that matter* at least to the world of the game. This is the essence of endogenous value. In the game, *your* actions make the difference between life and death, good and evil.

It is interesting to note that in many games, survival is the underlying concern even if metaphorically. Pac Man, Centipede; of course the host of first-person shooters including Doom and Delta Force; even *Tetris* poses the underlying question: "How long can you survive?" For other games such as Sim City, and the many role-playing games, expansion of agency seems to be framed more in terms of thriving than surviving.

Moreover, the notion of agency implies the reciprocal presence of both cause and effect. The living agent is not just a constructor of knowledge, nor is the agent "a cog in the wheel" acting according to its predefined role, but is a co-creator of reality. Reality is acting upon and shaping the agent, but the agent is also acting upon and shaping reality. Human technology is the prime example of this co-creation. Technology depends upon the presence and predictability of reality; yet at the same time technology creates a new reality. In addition, as we shape technology; technology also shapes us (Heidegger, 1997). The issue of global warming would, perhaps, be a case in point.

This quick example highlights Holland's (1996) argument above that consequences of adaptive actions play out over different time scales. For example, the consequences of something simple like skipping lunch are of very short duration; whereas, the actions that have led to global warming began decades ago. The variable time scale of effects further highlights the value of appropriately anticipating the effects of a course of action. In this one can see the value of teaching: to illustrate the consequences of a course of action over a time scale that is not readily apparent to the agent. In this one can also see the value of learning: learning gives the agent the opportunity to anticipate a previously unanticipated effect and therefore shape a new reality. Thus the exercise of agency includes the need for knowledge, experience, sound judgment, creativity, and performance ability. The logical extension then, is that teaching and learning serve to expand agency. Consequently, I base this design theory upon this foundation.

Simulated Challenge and Learning

Another logical extension of this definition of agency, and the second foundational assumption is that valued learning becomes embodied. Learning that does not foreshadow an opportunity to exercise agency in a probable situation, is trivial. Like the Whopper or the Big Mac, whether I learn this or that—if it has no perceptible impact on my agency—may be simply a matter of taste, idle curiosity, or convenience. By way of analogy, we have systems for processing food; ideally, what is valuable for growth or maintenance is kept and what is not valuable (or harmful) is eliminated. We also have systems for processing information; likewise, what is perceived as valuable ideally is kept and what is perceived as not valuable (or harmful) is eliminated. Learning that is meaningful will eventually be enacted in the physical world. Therefore, if the construct or performance promises increased ability to anticipate and act meaningfully in a situation one might reasonably encounter, it is worth incorporating (figuratively and literally) into one's repertoire of available constructs and abilities.

Providing an opportunity to "test drive" the knowledge or performance would help the learner assess its value in realistic terms. To the extent that the knowledge or performance holds the promise of agentive value, it is worth continued investment. It is, of course, preferable to test the limits (the range of value) of the knowledge or performance without the risk of real consequences. Further, appropriately incorporating the construct or performance takes time and practice. In other words, *risk with recoverability* is an ideal feature of the learning experience. Therefore, the *simulated* challenge of endogenous value provides the optimal venue for evaluating and embodying learning. (Therefore, the instructional design theory is called Challenge-driven Instructional Design.)

Endogenous and Exogenous Value

From my review, I have been able to identify only one *inherent* characteristic that is different for games and instruction. This fundamental difference is *endogenous value* versus *exogenous value*. Endogenous value, value within the self-contained system, is sufficient for games; it is not sufficient for education. The value of what is learned in the game need only remain in the game and the game is still successful. For example, I have learned how to perform a power slide in *Mario Kart* which is very valuable inside the game; this new skill, however, does not help me drive on the freeway. Thus, the sole requirement of endogenous value is why games can be completely unrealistic.

Therefore, the third assumption is that a goal of education is to provide exogenous value, or value outside the self-contained game. Instruction should prepare the learner for the exogenous challenges and situations of the real world. Thus, instruction cannot sacrifice exogenous value for the purpose of engaging learners and still be successful. This difference may be at the heart of the limited success of edutainment (Fortugno & Zimmerman, 2005). It may also be this difference that underlies some of the difficulties of integrating computer games successfully into instruction.

In my experience as a learner and as a practicing instructional designer, I have found that most instructors are intuitively aware of the exogenous value of what they teach. It often happens, however, that they fail to communicate this value to students. Consequently, learners cannot always make the connection themselves (Hake, 2002; Marks, 2000; Tobias, 1992).

However, instruction also cannot ignore endogenous value. I would assert that the best way, especially early in the learning process, to demonstrate exogenous value is to find a setting and situation that illustrates endogenous value. For example, the thinking skills emphasized in both Virtual ChemLab and Bio 100 are given endogenous value inside the setting, but also have exogenous value beyond the time spent with these cases.

Both the design of instruction and the necessary adjustments in the classroom are improved by explicitly specifying the challenge and its exogenous and endogenous values. Further, these values should be communicated explicitly to students as well. Therefore, Challenge-driven Instructional Design continues to specify a goal of endogenous value, although attention should be paid to real world ties outside the instructional experience.

To summarize the foundational assumptions of Challenge-driven Instructional Design are 1) the purpose of learning is to expand the agency of the learner; 2) simulated challenges represent an optimal method for agents to evaluate and fully incorporate learned knowledge and performance; and 3) learning experiences should demonstrate endogenous value to prefigure exogenous value.

The Instructional Design Theory of Challenge-driven Instructional Design

In this section, I will outline the core components and operational principles of the design theory. Further, I will outline an iterative design approach directed by priority rather than by linear process.

Core Components and Operational Principles

In this dissertation, I have defined and illustrated the core design components of engaging experiences. These are also the core design components of Challenge-driven Instructional Design. For convenience, these are reviewed again in Table 12. These core components and their associated operational principles provide a beginning framework for this theory.

Table 12.

Core components and operational principles of Challenge-driven Instructional Design

Core Design Component	Associated Operational Principle
Meaningful Challenge An achievable goal of endogenous value that entails conflict constrained by operational rules and limited resources.	Variable Challenge Cycles of provocation and resolution that repeatedly invite participants to develop and test their adaptive capabilities.
Self-consistent Setting A co-constructed imaginative or physical subset of reality defined by constituative rules, and represented thematically.	Thematic Signaling Narrative descriptors that consistently evoke the constructs of the setting.
Agentive Means A core performance and associated means through which to develop and demonstrate sound judgment and effective action.	Core Performance A focused, relatively automatic set of anticipatory, adaptive abilities required to successfully meet the challenge
Embedded Helps Resources or mechanisms within the designed experience that provide a reasonable assurance of safety, and that assist, encourage, or guide the development of adaptive abilities.	Recoverability Mechanisms that allow the participant to overcome mistakes or that restore the participant to a prior status and encourage continued effort and experimentation.

Challenge-driven Instructional Design asserts that crafting a *meaningful challenge* within a *self-consistent setting* that provides the *means* and the *embedded helps* to support agents' exercise of judgment and action provides an environment in which learners can test and expand their agency. These four components must work together consistently and congruently to achieve high levels of engagement. The *meaningful challenge*, however, is the central mechanism by which learners' evaluate their developing agency.

Application of the theory would be most useful in situations where motivation and engagement are low. When learners already perceive value, such as in courses for a major, or a gathering of professionals, this theory would be helpful, but may not be as necessary. Therefore, this theory would be particularly useful for general education courses for example.

Design Process by Priority

I concur that design is not a procedural, but an iterative process (see Darke, 1979; Gibbons, 2000; Silber, 2007; Simon, 1996; Van Aken, 2004). Therefore, I propose an iterative design process guided by priority rather than by procedure.

Recently it became apparent that in designing Virtual ChemLab and Bio 100, we had intuitively settled on what Darke (1979) calls a *primary generator*. In explaining the primary generator, Darke (1979) argues that experienced designers do not begin with an exhaustive analysis of the design problem. Rather, they select an initial organizing and constraining concept that offers an entry point to the design problem. Darke (1979) calls this organizing concept the primary generator. The primary generator can be different for different situations even within the same class of design problems.

It was interesting to me to realize that in the design of each of these instructional cases, we quickly settled on a primary generator. In the case of Virtual ChemLab, *core performance* served as our primary generator. In the case of Bio 100, *meaningful challenge* became our primary generator. In both cases, *core performance* and *meaningful challenge* were the highest priority. The emphasis in design was to maintain a tight correspondence between the *meaningful challenge* and the *core performance*. The *self-consistent setting* and *embedded helps* were still essential, but they were subordinate to, and designed to support, the *meaningful challenge* and the *core performance*.

Therefore, I recommend that designers start with one of the following two questions: "What *meaningful challenge* will this subject help learners face in the real world?" or "What *core performance* will learners need to develop in order to meet the type of challenge this subject represents?" The next priority is to answer the second question based on the answer to the first. The answers to both of these questions will often suggest appropriate directions for the setting and embedded helps.

Again, all of the components must work together. Thus, considering one aspect of the design may suggest new directions or revisions to another aspect. Nonetheless, what should always retain priority status is the tight integration between the *meaningful challenge* and the *core performance*.

Implications of the Theory for Implementation in Instruction

This instructional design theory is not without significant implications for instruction. Three salient implications from the emphasis on agency and on challenge are 1) that the subject matter of a discipline is a means to expand agency and not an end in itself; 2) that the roles of instructor and learner shift which does not occur painlessly for either party; and 3) that grading practices should provide opportunities to learn and recover from previous mistakes.

Change in Role of Subject Matter

It is my experience that for some instructors it is an unstated assumption that successful teaching occurs when learners accurately acquire the subject matter. Under this assumption, the purpose of textbooks, lectures and exams is to accurately and logically describe the subject and to test the accuracy of learners' acquisition of the material. Under the assumptions of Challenge-driven Instruction Design, the subject matter is the means that learners will use to expand the breadth and the depth of their agentive repertoire (see Barr & Tagg, 2000, 1995).

The change from end to means may appear to relegate the subject matter to a lesser status. However, I would argue that ultimately it increases the probability that learners will perceive more value in the subject than they might have otherwise. If learners can experience a situation in which they might find themselves, and in which the subject matter is pertinent, then it would stand to reason that the perceived value of the subject would be enhanced.

Change in Roles of Instructors and Learners

Under the assumptions of the theory, the role of the instructor is different. These changes are similar to changes required by learner-centered teaching (see Benjamin & Keenan, 2006; Weimer, 2002). One of the possible perceptions is a loss of status and a loss of control over the instructional setting (Benjamin & Keenan, 2006; Burdett, 2007). With a traditional lecture format, the instructor is the expert; the subject matter is well-known and predictable to the instructor; and by virtue of expertise in the subject, the instructor has substantial control over the entire proceedings of the course. In Challenge-driven Instructional Design, the instructor is primarily a source of help and encouragement (for a discussion of instruction as help see Inouye et al., 2005). This requires a paradigm shift and practice from the instructor.

Challenge-driven Instructional Design shifts a substantial responsibility for learning to the learner similar to other inductive instructional methods (see Prince & Felder, 2007). For many learners this is a welcome change. However, this requirement is new and uncomfortable for many other learners (Duch, Groh, & Allen, 2001; Prince & Felder, 2007; Woodfield et al., 2005; Woodfield et al., 2004). For these learners, additional instructional support may be necessary. Further, Duch et al. (2001) indicate that learner resistance to this responsibility may not be entirely overcome. This is confirmed by anecdotal evidence from instructors I have worked with.

Change in Assessment and Grading

As indicated above, risk without recoverability encourages conservative strategies. One of the most careful, plodding strategies in instruction is found in the question, "Will it be on the test?" Some grading practices penalize mistakes rather than provide a substantial opportunity to learn. Generally, once the assignment is graded that score is unchangeable and it affects your cumulative grade at the end of the term. In some cases there is not even a theoretical way to demonstrate improvement since that performance will not be assessed again. Grading practices of this type discourage risk-taking; therefore, students resort to conservative strategies.

The assumptions of this theory indicate that grading practices should emphasize acquired knowledge and ability toward the end of the learning experience. That does not imply the lack of assessment throughout the course, but rather the purpose of this assessment is *feedforward* (see Carless, 2007): to encourage continued experimentation and learning. For example, evaluators of Virtual ChemLab indicated that the ability to try something out without both the messy consequences of a real lab and risking a good grade was part of the "fun" of the simulation and resulted in better understanding of the chemistry (Moore, 2002; Woodfield et al., 2004). It should be noted that *recoverability* does not imply extra credit or bonus points to get a student's grade up. *Recoverability* is intended to encourage the learner to take the risk to really learn.

The design of *recoverability* may also impose the biggest logistical difficulty. For many computer-based instructional activities, such as Virtual ChemLab, this may not be true; the necessary corrective steps can be facilitated by the software. But providing *recoverability* was a significant issue in Bio 100. Reviewing and giving suggestions for improvement in this case relied heavily on instructors and teaching assistants. Therefore, feedback was not as immediate, and the number of practice opportunities was limited. For some instructional situations *recoverability* will require moderation and creativity.

Further Research and Development

I submit that Challenge-driven Instructional Design holds promise as an instructional design theory. The theory needs to advance to the next level of verification by developing instructional materials explicitly based on the theory and evaluating these materials for both learner engagement and learning effectiveness. In addition, continued analysis of the theory is needed to identify additional sub-components and associated operational principles. Further research would also be warranted around the question of implementation of challenge-driven materials and instruction in the classroom.

Conclusion

The issue of learner engagement is an important question for education and for instructional design. The purpose of this dissertation was to better understand the design of computer games in order to better understand the design of engaging experiences. By reverse engineering the design of computer games, core design components of engaging experiences were identified. Evidence was also provided that these principles could be employed in the design of instruction. A tentative instructional design theory called Challenge-driven Instructional Design and design considerations for the theory were proposed. Finally, suggestions were made for continued development and research of the theory.

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