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**SERIOUS GAME DESIGN PRINCIPLES:
THE IMPACT OF GAME DESIGN ON LEARNING OUTCOMES**

by

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A Dissertation Submitted to the Faculty of
Old Dominion University in Partial Fulfillment of the
Requirements for the Degree of

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August 2012

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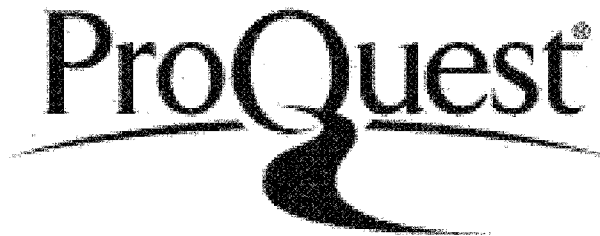


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ABSTRACT

SERIOUS GAME DESIGN PRINCIPLES: THE IMPACT OF GAME DESIGN ON LEARNING OUTCOMES

Michael W. Martin
Old Dominion University, 2012
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This dissertation examines the research question “How do video game design principles affect learning outcomes in serious games?” This research first develops a theoretical foundation concerning the meaning of the terms “game” and “serious game”. This conceptual clarification is broken down into analytic propositions, which state that games have participants, rules, goals and challenges, and synthetic propositions, which state that the games should be intrinsically compelling, provide meaningful choices, and be self encapsulated. Based on these synthetic propositions, three hypotheses were developed. The hypotheses are that games with an enhanced aesthetic presentation, more meaningful choices, or provide player competition will elicit higher learning outcomes than identical games without these factors.

These hypotheses were tested via a quantitative experiment involving 172 undergraduate students in the Old Dominion University Chemistry Department. The students were asked to play a chemistry-oriented serious game entitled Element Solitaire©, which was created by the research author. The students were randomly given different treatments of the Element Solitaire© game to play, and the difference between their learning outcomes were compared. The experimental results demonstrated that the aesthetic presentation of a game can have a significant impact upon the learning outcome. The experiment was not able to discern significant effects from the choice or competition

conditions, but further examination of the experimental data did reveal some insight into these aspects of serious game design. Choices need to provide the player with options that have a sufficient value that they will be considered and the application of competition within games needs to be judiciously implemented to promote a positive affect for all players.

The results of the theoretical foundations and empirical evidence were then combined with additional theoretical research to develop a set of design principles and a proposed serious game development process. These guidelines were researched and examined via the design and development process of several serious game prototypes and the examination of a large body of existing serious games. The end result is a practical procedure that is rooted in theory and quantitative experimentation.

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CHAPTER 1

INTRODUCTION

For the past decade and a half, there has been a growth in interest in the concept of serious games. The growth in the field parallels the ascendancy of video games in modern culture. In the mid 2000's, the commercial software entertainment industry eclipsed Hollywood in terms of revenue [1], and in the 2008, sales of video games surpassed the global sales of DVDs [2].

In some ways, the “serious games” field is the aspiring successor to the somewhat tainted “edutainment” software movement [3]. Whereas edutainment may have been seen as the worst of game development, serious games intend to capitalize on the explosive growth of the commercial software entertainment industry. Many of scholars and authors have expounded upon the potential and perceived benefits of serious games [4-9]. However, there is a shortage of experimental data to support these claims. There are many presumptions regarding the possible merits of the field, but there is not a large body of data from which to verify that the merits exist, and do indeed result from serious game usage. Further, while the theorized or anecdotally observed benefits are well detailed, there is little discussion how to actually create serious games and engender the described benefits. This shortfall has been remarked upon in various symposiums and forums, and various recommendations have been presented to help close this research gap [10-13]. D. Williams also makes a compelling case that there are two different approaches to the academic research of games[14]. There are, as Williams describes, the “social science” approach, which is concerned with the cause and effect of game usage,

and the “humanist” approach, which is concerned with the significance and context of games. Williams notes, however, that the two distinct approaches have a tendency to diverge.

1.1 Purpose and Rationale

This dissertation seeks to make a contribution to the existing body of quantitative data, while keeping Williams’ admonishment in mind to synthesize various research fields in the exploration of serious games. It begins by examining the meaning and connotations of the concept of serious games. From that theoretical foundation, the work identifies three specific entertainment game design principles, and examines them through the lens of educational and instructional design theory. This research then tests the derived theory in experimental settings to quantify the effects of these design principles might be upon serious games and learning outcomes. The culmination of this dissertation is to present serious game design principles and process built upon a theoretical foundation and supported by quantitative experimentation data.

The idea of learning in games is not limited to games played on computers, and there are many examples of non-computer based educational games. However, this research will limit itself to dealing with computer based serious games.

1.2 Research Questions

The fundamental issue addressed by this research is the examination of how games affect learning outcomes. The implicit claim within this research area is the basic assertion of serious games: that game play results in learning outcomes. Game play,

however, is a very broad term, and in order to harness its potential, it is helpful to first examine what the concepts of games and serious games mean, and to try and understand how gameplay is created. By exploring game design, it is possible to understand how game play is created. In turn, it is possible to examine what type of game play is most conducive to learning.

Commercial video games have a history extending back to 1971, and have grown immensely over the years [15]. As the budgets, scope, and cultural prominence of digital entertainment games expand, the process involved in creating games is becoming increasingly codified. Prominent game designers such as Chris Crawford, Jesse Schell, Raph Koster, Katie Salen and Eric Zimmerman have studied, recorded and organized their understanding of the game design process and first-hand accounts of game development experiences for the benefit of the wider game development industry [5, 16-20]. This dissertation will explore this body of game design expertise and examine whether the implementation of specific game design principles in a digital serious game can affect the learning outcomes derived from using that game.

A myriad of potential game design principles exist, and exploring all possible game design heuristics would be an immense undertaking. Jesse Schell alone, in his book *The Art of Game Design*, describes 100 possible principles [19]. In order to provide a reasonable scope for the research, this dissertation will limit itself to examining three game principles which have been assessed as being critical to the very core concept of what constitutes a serious game. These three principles are Game Aesthetics, Player Choice, and Player Competition. Chapter 2 provides a detailed exploration of the

definition of a serious game, including the derivation of the three aforementioned principles. Put more specifically, the research question being explored is:

How do the following game design principles affect learning outcomes in a serious game?

- *Game Aesthetics*
- *Player Choice*
- *Player Competition*

1.3 Dissertation Organization

This dissertation is organized into seven chapters which describe two nested research efforts. These research efforts are to 1.) Conduct empirical quantitative research into the effects of specific game design principles upon learning outcomes, and 2.) Develop a proposed game design process based on the quantitative research developed in the first effort.

Chapter Two describes the theoretical basis which serves as a foundation for the experimental work. This chapter is primarily concerned with synthesizing conceptual clarifications for the concepts of games and serious games. These conceptual constructs then inform the development of the hypotheses derived from the research question.

Chapter Three describes the proposed experiments in detail. This chapter describes the Design, Variables and Treatments, Research Participants, Measures, Analysis, and Limitations of the experimental work. It also covers the pilot study used to establish a foundation for the experiment, as well as a detailed description of the serious game used in the experiment.

Chapter Four discusses the results of the experiment. It presents the experimental findings as well as the statistical analysis. This chapter also includes a brief discussion of the implications of the findings within the context of the experiment.

Chapter Five discusses additional theoretical research which serves as a basis for creating a broader serious game design process. This research is not limited to the factors analyzed in the experiments, but serves as a complementary body of work which helps paint a broader view of the serious game design process.

Chapter Six presents an additional literature review and a theoretical synthesis of the empirically derived game design principles to create a serious games development process. This chapter also verifies the utility of the game design process and principles by examining them in the context of several serious games development efforts, as well as a survey of existing serious games.

Chapter Seven presents the dissertation conclusion. This chapter summarizes the findings of the research efforts, and presents the resultant serious game design process. It also includes an extensive look at possible lines of future research.

CHAPTER 2

THEORETICAL BASIS FOR EXPERIMENTATION

The first step in this research is to identify the basic terms and examine their meanings. The two basic terms of interest are “serious games” and “games”. This chapter discusses some existing definitions for the terms, as well as some of the issues raised in those definitions. It then builds upon those concepts to develop theoretical foundations helpful in addressing the specific research questions stated in Chapter 1. Based on these research questions, hypotheses are formed to serve as the theoretical basis for experimentation.

As a caveat, this research and discussion is limited to dealing with games that are computer based or digital. This choice in research scope has no reflection on the viability or utility of non-digital games and serious games. It is certainly possible to create both games and serious games that don't use a computer, and there are relevant game design principles in the field of non-digital, or “analog”, game design. Indeed, many of the books which teach digital game design principles by having learners examine and build non-digital games [18-21]. However, the focus here will be limited, as much as practical, to digital games and digital serious games.

2.1 Examining the Concept of Games

Merriam-Webster's online dictionary provides several relevant definitions of the term “game”:

“3a(1) : a physical or mental competition conducted according to rules with the participants in direct opposition to each other...3a(5) : the manner of playing in a

contest... 3c(2) : any activity undertaken or regarded as a contest involving rivalry, strategy, or struggle” [22].

In addition to this simple dictionary definition, there are also numerous scholarly works dedicated to analyzing the subject of games. Caillois described games as being activities that are fun, distinct, uncertain, non-productive, rule-driven, and fictitious [23]. Clark Abt, in 1970, described games as an “activity among two or more independent decision-makers seeking to achieve their objectives in some limiting context” [24]. More recently, Katie Salen and Eric Zimmerman describe “artificial conflict, defined by rules, that results in a quantifiable outcome” [20]. Marc Prensky presents a hierarchical definition of games which distinguishes games from other forms of play by asserting that games have rules (Prensky, 2001). Jesper Juul’s analysis of games [7, 25] echoes Prensky’s in its hierarchical categorization.

While each definition has its own nuances, in general, they all trend towards a set of recurring and common definitional components. The recurrent components of a game may be summed up as **participants, goals, rules, and challenges**. The participants have goals within the game, which they try to achieve via a set of rules. The rules define the participants’ interactions, and in the application of these rules, the participants try to overcome challenges in order to achieve their goals. These components are intrinsically true to the definition of what a game is, and may be considered analytic propositions for the term “game.”

2.2 Examining the Concept of Serious Games

First and foremost, for the purpose of this work, serious games will be considered to be games whose learning benefits have value beyond the game. In training parlance,

this may be referred to as *training transfer*. Stated another way, serious games are games in which the learning that occurs during game play is transferable outside of the game.

This description begs the very question of learning as it relates to games, so it is worth examining that basic premise. From anecdotal observation, it is arguable that game players learn something in every game. This is true as long as the player's performance correlates to the game outcomes, and the player's performance is skill rather than luck based. If the preceding is true, and the player is able to improve their performance, then learning has occurred. If this were not true, then a player's performance on a game would be the same the first time they played as it would be the last time they played. It is only by learning the nature of the game that the player can improve their performance.

The works of several authors in the field of "play theory" support this perspective. In the 1961 book *Man, Play and Game*, Roger Caillois characterizes many sociological and cultural constructs as the result of lessons learned in play, thus also supporting the concept that learning occurs during play [23]. More recently, Raph Koester makes a case that fun is the direct result of our brain's learning [5]. The concept of learning a game also features prominently into Jesper Juul's work, *Half-Real: Video Games Between Real Rules and Fictional Worlds* [25]. Juul explores the issue from the game design standpoint in his book, and specifically addresses the dichotomy of combining fantasy and reality in video games, where you have fantastical and imaginary setting with fixed rules superimposed over them.

Accepting the premise that game play engenders some type of learning, serious games differ from entertainment games by the utility of what is learned while playing

them. Most of the time, what the players learn in entertainment games is useless in the real world. Players of Nintendo's famous game "Super Mario Bros." [26] might learn that touching a mushroom will kill you, but that you can jump on top of one to safely squish it. Learning these aspects of the game helps the players perform better in the game, but this knowledge lacks utility in the real world. The learning does not transfer well outside of the game context. Serious games, in contrast, would be those in which the aforementioned learning does transfer positively outside of the game.

There are a number of established serious game authorities, however, that take a different approach. Rather than defining serious games in terms of what they do, however, these people and bodies define serious games in terms of their intent. One of the most succinct definitions for serious games is found on the Michigan State University Serious Game Design Program webpage:

"Serious games are games with purpose beyond just providing entertainment." [27]

Put another way, "serious games" are games played for a serious intent or reason. Mike Zyda, Director of the University of Southern California Viterbi School of Engineering's GamePipe Laboratory, proposes a similar definition, though with more detail as to the nature of the purpose:

"Serious game: a mental contest, played with a computer in accordance with specific rules, that uses entertainment to further government or corporate training, education, health, public policy, and strategic communication objectives." [3]

Consideration of the intent of learning in serious games potentially raises more questions than it answers. Who endows a serious game with this intent? Is it the player, the designer, or some third party? Does the player have to know that they are learning in

order for something to be considered a serious game? How does recognition of the learning process impact on the learning outcome?

Many serious games tend to advertise their learning potential forthrightly to all parties involved. It is not hard, though, to imagine a scenario in which learning takes place unbeknownst to the player. Two science fiction works, *Ender's Game* and *The Diamond Age*, depict such scenarios [28, 29]. In each, the main characters are young children who learn important lessons through various games, though they are unaware of their educational benefits. Though these are works of fiction, it is easy to imagine that many edutainment software programs or serious games presented to learner, be they young or old, teach their players without the player's explicit acquiescence. Indeed, the predominant and highly contentious thesis of anti-game critics is the charge that games teach young players unhealthy or antisocial attitudes and behaviors without their knowledge or intent [30, 31]

Conversely, there are plenty of examples of third parties who have adapted games to teach themselves something, even though the original designers concerned more with entertainment, rather than education. *MarineDoom* is a famous example, in which U.S. Marine Corps personnel began using the entertainment game *Doom* to teach tactics [32].

The concept of intent can be vague and not readily observable. For the purposes of this research, the primary delineation between games and serious games will be the transfer of learning to the player, rather than the purpose motivating the game. This helps avoid the sticky issues of intent, and focuses on the measurable outcomes of the play instead. However, while this accounts for the "serious" part of the term "serious games,"

the definitional exploration is incomplete without an examination of that the term “game” means.

2.3 Analytic and Synthetic Propositions of the Terms

The concepts discussed above help create a baseline of understanding for the concepts central to this line of research. However, in trying to apply these concepts to aid in analyzing serious games, shortcomings in the ontological constructs become apparent. The decompositional description of a game (games have **participants, goals, rules, and challenges**) may serve well as a point of reference. As analytic propositions, these components are presented as intrinsically true. Yet at the same time, they are also potentially too broad as to be useful in a detailed discussion of games and serious games. They encompass the concepts in widely applicable terms, but as a result, may also be valid for things which are not games. For example, a game of football has participants, goals, rules, and challenges. Arguably, the chore of mowing the lawn also has all of these components. It can be assumed that most people would not consider mowing the lawn to be a game, even though it may be interpreted as having all the components that listed above comprise a game. This does not necessarily invalidate the definition as much as it highlights that this list alone is not sufficient information to distinguish games from non-games. These components help in understanding what a game is, but not necessarily in understanding what makes a game unique from other activities.

The addition of three synthetic propositions can improve the utility of the analytic description of games. These characteristics are not intrinsically true of the term game, and it may be possible to find exceptions to these propositions. They do, however, add

descriptive power to the definition that can help better frame the concept. The synthetic propositions are that games should:

- Provide meaningful choices to the user.
- Be self encapsulated experiences.
- Be intrinsically compelling.

It is worth repeating that these propositions are not necessarily true in regards to all games. Indeed, it is possible to find examples of commonly accepted games which fail one or more of these criteria. However, in most instances, these are either expectations that prove the point, or parochial applications of the ‘game’ label. These synthetic propositions paint a more insightful picture of the term ‘game,’ and seem especially relevant for serious games within the context of this research.

They also serve an important function in helping to differentiating games from non-game activities. In some regards, it seems as if the field of serious games struggles a bit with an identity crisis. There are many examples of endeavors which label themselves “serious games”, yet under closer examination, seem to fall short. In doing so, these efforts miss out on potential benefits of what a serious game could be. The synthetic propositions presented above can be used to identify these shortfalls, and thus potentially identify ways to enhance the serious games. The following sections explore each of the propositions, and provide examples of non-games which lacked the relevant quality.

2.3.1 Meaningful Choices

There are a number of computer based learning or training applications which have seized upon the serious games trend, yet take short cuts to create what they believe

is a serious game. These efforts apply game-like facades to traditional computer education activities in the hopes of reaping the unique benefits that games can provide. Certainly, many traditional computer based learning activities fulfill the analytic propositions for games provided above. But as with the example of mowing the lawn, it is worth considering if these are good applications of the term “game.”

A quiz or test, common to most educational systems, is a prime example of an activity that can satisfy the analytic propositions of a game, yet still fall short of the meaning of the term. A quiz has rules (fill in the blank, multiple choice, etc.), it has goals (to score the highest score possible) and conflict (the difficulty of the questions). Though such assessment tools are not typically thought of as games, some educational applications have taken to decorating test-like experiences with game-like veneers, such as cartoon graphics and sound effects, and labeling them serious games. Two examples of this practice are Grammar Gorillas [33], and Snork’s Long Division [34]. Grammar Gorillas has the player select specific parts from a sentence. Snork’s Long Division has the player simply perform long division. Both are self declared serious games, but they seem to fall short of what would normally be considered a game.

In examining why these activities do not seem like games, it becomes apparent that at their core, these programs don’t provide the player with any meaningful choices. The user simply answers the question correctly or fails the question. While the students do choose how to answer the question, these choices are not meaningful in that there is only one correct answer, with no viable alternative. Raph Koster identified this pitfall in his book, *A Theory of Fun and Learning* [5]. Using Tic-Tac-Toe as an example, he

illustrates that the game ceases to be a game when the players learn that they have no choices. At that point, the game becomes a simple drill in the rote application of logic.

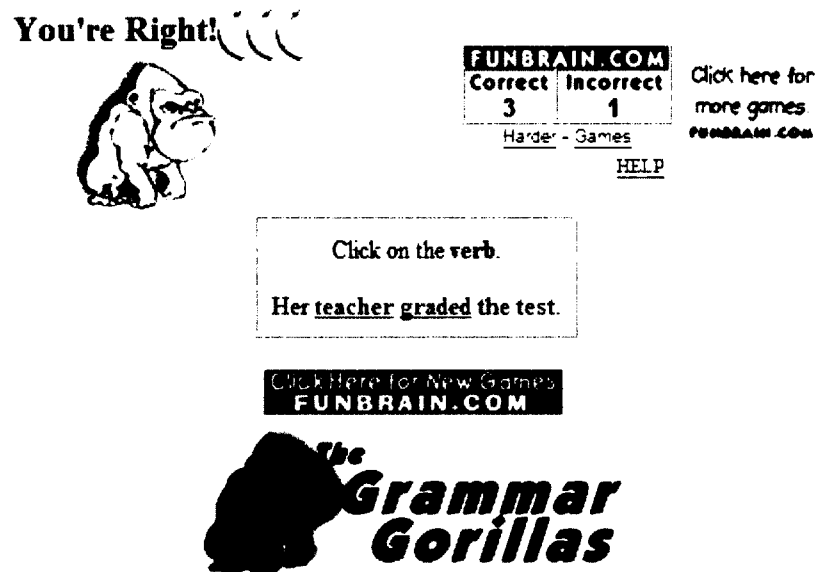


Fig. 1. Grammar Gorillas, by Pearson Education [33]

Further, by not providing meaningful alternatives, these software examples limit the potential for player interacts with the learning content, as described by James Paul Gee [4]. Gee describes his realization that:

"...video games create... a learning space in which the learner can take risks where real-world consequences are lowered." [4].

The lack of choice collapses the exploratory learning space, and deprives the player of the opportunity to reflect upon the information being presented and applied. David Shaffer argues that games have the potential to allow a more "authentic" method of learning than traditional schooling techniques because games set the stage for learners to think not only about what the right answer is, but also how they know an answer is

right and what is the process by which they arrive at that answer [35]. There is a diminished incentive and opportunity for the learner to engage in a metacognitive assessment of their understanding of the learning content. Quizzes inhibit the learner interaction within the defined learning space to a single correct answer. All other options are simply incorrect. They test the user's knowledge, but do not seem to engender the same degree of introspection that a wider array of viable choices might. Carefully worded choices can make it more difficult to discern the right answers from the wrong ones, but the meaningful interaction with the learning content is still stifled.

In order to provide that sense of freedom that fosters exploration and learning, as Gee and Shaffer suggest, games may be better served by adhering to game designer Sid Meier's dictum that games are a "series of interesting decisions" [36]. Meier is renowned for his highly complex strategy games. It is not quite necessary to achieve those levels of intricacy in game design. Rather, the sentiment of providing players with meaningful choices, without a clearly dominant option, should be adhered to regardless of complexity. The term meaningful, in this context, refers to having multiple viable alternatives which each present unique consequences. Each consequence has its own benefits and detriments, but none being an obviously superior choice to the others.

Some activities offer no meaningful choices, either because there are no really choices, or the choices are meaningless. The quiz trend towards offering no real choices, as the player's only viable option is to answer the question correctly. At the other extreme, some entertainment games offer a wide array of choices that effectively have no consequence. For example, many games allow the player to visually customize their character, but ultimately these choices have no effect on the game play. A meaningful

choice allows the player to select between viable alternatives, without any clear optimal choice. This allows the player to freely explore the conceptual space created by the game.

2.3.2 Encapsulation

The next example of non-games is the directionless open sandbox experience. Sandboxes are commonly found in training simulations used for police and military. They are programs that create worlds in which typically groups of individuals engage in educational or learning scenarios, and typically take the form of simulation designed to provide learners with an alternative to costly or dangerous real-life activities.

Such programs have been in use for several decades. One of the first was SIMNET, which was developed and deployed in the early 1980's [37]. For many years, such virtual reality training programs required specialized hardware and software, but were still relatively inexpensive in comparison to the resource cost of conducting the training using real world equipment and locations.

Recently, however, the commercial entertainment software industry has proven that high quality sandbox experiences can be delivered on commercially available hardware and software. Games such as Electronic Art's Battlefield series [38] and Activision's Call of Duty series [39] provide immersive virtual combat experiences, and the U.S. Military, for obvious reasons, has been eager to harness the power of these types of games for training purposes. Because of the advances in commercial software and hardware, specialized simulation equipment is no longer a requirement, and these

experiences can be delivered for even less cost and often adaptability than simulations using specialized hardware and software.

A prime example of the U.S. Military's efforts to capitalize on the power of these games is the adoption of a program called Virtual Battlespace 2 (VBS2) [40]. VBS2 is a training program developed by Bohemia Interactive, a company whose roots were in developing commercial entertainment software. Bohemia developed a number of games, including a tactical virtual reality shooting game called Operation Flashpoint. VBS2 is based on the Operation Flashpoint game, and is designed to run on common desktops and laptops. Because the program shares software technology with Bohemia Interactive's commercial game, Operation Flashpoint II, there is a natural inclination to call VBS2 a serious game.

However, VBS2 differs from traditional games, including Operation Flashpoint II, in a very important way. VBS2 is designed to host multiple networked users in a virtual training environment. In game terms, it would be considered a large multiplayer game. Unlike games, however, this experience is not a closed system. The multiplayer sessions don't have scores, or internally defined objectives within a game structure. They lack the framework associated with traditional multiplayer games. A learner cannot start a VBS2 session and know what to do. Instead, VBS2 sessions are designed to be administered by teams of instructors, who take on the duties of giving the players objectives, assessing their performance and providing them with feedback. In commercial terms, the game would be considered an undirected, open world experience, similar to Second Life [41]. Players can interact, but in order for the interactions to have a purpose, the participants

themselves have to overlay meaning onto those interactions, or have meaning ascribed to their performance by external observers.

In traditional video games, the valuation of player interactions is adjudicated by the game itself. Further, a player can play the game entirely by himself or herself. This concept even applies to multiplayer games. A player sitting down with the commercial version of the Operation Flashpoint can play the game by themselves, even when engaging in multiplayer sessions. They can join a multiplayer session with no prior coordination, receive objectives, play the game, get feedback from the game on their performance, and then quit when they desire. Granted, in games which are exclusively multiplayer in nature, this assumes a robust network structure with available sessions, but given that assumption, there is no overhead to playing the game other than the player and the game itself. VBS2 and other serious games like it lack this fundamental game characteristic. It is a simulation which cannot be engaged in without someone external to the game session providing some sort of structure.

If VBS2 was able to provide that overarching structure within the game, then users could train at their own pace, learning the materials as appropriate to their individual skills. Targeting training at the individual level could greatly increase the user engagement and ultimately the effectiveness of the training. No longer would quick learners be held up by the slow members of traditional classes or training groups, nor would the slow learners be dragged along faster than they can assimilate the material. If the instructional framework were properly embedded, then the serious game would be a self encapsulated experience, just as commercial video games are.

2.3.3 Intrinsically Compelling

The last synthetic proposition of games concerns the subjective concept of “fun”. Some of the definitions of games mentioned previously, such those of Abt, Caillois and Zyda, make specific reference to entertainment or fun. Other definitions omit such concepts, perhaps due to their highly subjective nature. However, as a basic metric of value for entertainment games, it is undeniable that fun is an aspect of the game concept.

Consumers pay money to play games, not because the games provide some sort of extrinsic reward, but because the game experience, itself, is rewarding. The intrinsic value of the game experience outweighs any extrinsic benefit or detriment caused by playing the game. The games are therefore intrinsically compelling.

The phrase “intrinsically compelling” encompasses the concept of fun, but it also makes room for other aspects, such as the satisfaction of overcoming a challenge, or earning a reward. It is not entirely implausible that certain games might be intrinsically compelling without being entirely fun. For example, many Massively Multiplayer Online Role-Playing Games (MMORPGs), like World of Warcraft [42], routinely include what player communities refer to as “grinding.” Grinding is a low risk, low reward way to gain benefits that typically involves tedious and repetitive activities. While these activities may not be enjoyable, accomplishing them grants the player in-game rewards. It is a significant component of a very successful game genre which is not normally deemed as fun[43]. Yet for the players who spend hours doing it, it clearly is intrinsically compelling.

Regardless, of what creates that intrinsic compulsion, be it fun, the feeling of achievement, or some other factor, this intrinsic compulsion and educational value do not

necessarily compete. Raph Koester proposes that one form of fun is, in fact, the brain's reaction to learning [5].

From a practical stand point, a player who feels intrinsically compelled by a serious game is more likely to engage with the game, and therefore, assuming the serious game is designed well, more likely to engage with learning content.

2.4 Summary of the Conceptual Description

The preceding discussion has explored the nature of games and serious games, and presented some descriptions intended to aid in classifying and developing serious games. Accordingly, games are characterized by both their analytic and synthetic propositions.

The analytic proposition of games is that they have:

- Participants
- Goals
- Rules
- Challenges

These propositions are held to be true for all games. However, as games manifest in a wide variety of forms, these propositions lack specificity and discriminatory power. All games contain these elements, but based solely on these elements, it is difficult to distinguish some games from non-games.

In order to compensate for this shortcoming, the synthetic propositions are presented to add descriptive and discriminatory power to the description of games.

These propositions state that games should:

- Being intrinsically compelling
- Having a variety of meaningful choices
- Being self encapsulated

These propositions are less concrete than the analytic propositions, but they help contextualize games, and provide a basis from which to judge whether something is a game or not. These propositions are drawn from the theoretical discussion above, and this research develops experimental data to empirically examine these propositions, and provides a practical serious game development process which helps ensure that these propositions are incorporated into the end product.

It is worth reiterating that the preceding examination of the meaning of these pertinent terms is not intended to provide authoritative definitions. That objective is well beyond the scope or influence of this body of work. Rather, this theoretical basis is intended to clarify the concept of games and serious games within the context of the research question. The synthetic and analytic propositions provide a theoretical foundation from which to base the remaining research in this dissertation.

2.5 Hypotheses

The hypotheses for the quantitative portion of this research are drawn directly from the synthetic propositions presented above. Specifically, they are drawn from the propositions regarding game aesthetics and the presence of meaningful choices. The synthetic proposition that games are self encapsulated is not explicitly tested, as a matter of practical limitation to the research methodology. The encapsulation proposition is more intrinsic to the form in which the game would be delivered. An argument could be

made that the act of providing a subject group with a serious game on a given topic is a de facto test of encapsulation. The fact that a population might or might not use the game without any external force compelling their participation speaks to the fundamental nature of this proposition. Testing of this proposition would likely require a form of media comparison analysis between the game used in supervised and unsupervised settings. That particular line of research has a potential to become highly subjective, and dependent upon the quality of the supervision. For these reasons, this scope of the empirical research in this dissertation will exclude the encapsulation proposition.

The proposition that choice is a critical component of games and serious games makes a direct translation to a hypothesis. Because of the nature of programming a video game, the choices available to the player are easily quantifiable, and therefore easy to add and remove within the context of an experiment.

Slightly more challenging is the concept of addressing the notion of making a game intrinsically compelling. As described in the development of the proposition, “intrinsically compelling” incorporates a wide breadth of different aspects that might attract a player to a game. However, the most obvious might be the aesthetic presentation of the game. Video games are primarily a visual medium, and the quality of the graphics has been a significant driving force that has not only affected how games are made, but how computer hardware has developed over the last couple of decades [2, 44, 45]. The aesthetics of games are not restricted to graphics, however, and also include music sound effects, and even subtle reactions to how the player interacts with the program. The factors all combine to form the aesthetic presentation, and will be used as a hypothesis to assess these particular aspects of a game being intrinsically compelling.

Additionally, there is a growing trend towards making games multiplayer, so that the players are not just competing against the computer, but they are competing against each other as well. Traditional multiplayer used to almost exclusively involve the player directly competing against each other. However, Juul discusses the indirect social interactions that can occur in multiplayer games [46] and Schell addresses some mechanics by which this can occur, as well as the impetus driving players to engage in these activities [18, 19]. Papworth, a social media expert has discussed the particular trend of “leaderboards,” including its historical and non-digital precedents, as well as the impact upon online communities [47]. Leaderboards are similar to traditional scoreboards, but focus on the top performer in a field. The concept of community interaction the competition on a leaderboard will be used as another hypothesis to examine the concept of being intrinsically compelling.

The following three hypotheses are the results of the concepts and theoretical discussion presented above:

1. A serious game with added aesthetic features, to include graphics and music, will be more intrinsically compelling and result in higher learning outcomes than an identical one without music and graphics.
2. A serious game with meaningful choices will result in higher learning outcomes than an identical game without meaningful choices.
3. A serious game with competition will be more intrinsically compelling and result in higher learning outcomes than an identical one without competition.

The serious game being used to test these hypotheses should be consistent with the remaining assertions made previously. The game should have participants, goals, rules and challenges. Design implementations affecting how “intrinsically compelling” the game is and the number of “meaningful choices” available to the player become the independent variables for the experimental design. Through these hypotheses, this research will begin to gather empirical data to verify the theoretical construct of games and serious games.

CHAPTER 3

EXPERIMENT DESIGN AND METHODOLOGY

This chapter describes the experimental design used to test the research hypotheses. It begins with a description of the serious game, Element Solitaire©, and discusses the specific differences in the various treatment versions used to test the relevant hypotheses. It also details the pilot study used to test the feasibility of the experiment, and the changes made to the software and experiment procedures as a result of that initial study. Lastly, the experiment administration procedures are explained in detail.

3.1 Element Solitaire©

In order to test the hypotheses developed in Chapter 2, a game entitled Element Solitaire© was developed as a part of this research. The game is intended to facilitate the memorization of the positioning of chemical element locations within the periodic table of elements.

The periodic table is a basic chemistry reference, and catalogues all of the known and theorized chemical elements, arranging them from left to right, top to bottom according to their atomic numbers [48]. The rows of the periodic table are referred to as periods, and arranged to denote the respective energy levels of the element. The columns are called groups, and the elements within a group share specific valence electron configurations that are consistent. Periodic tables, such as the one shown in Fig. 2, also typically color code the elements into associated categories, dependent upon their

distinguishing properties. There are a number of such dynamics and relationships that govern the structure of the periodic table. An understanding of the periodic table itself is great aid in understanding the trends and properties inherent in individual chemicals.

The figure shows a periodic table where each element is represented by a small grayscale image of the element. The elements are arranged in groups (1-18) and periods (1-7). The Lanthanide and Actinide series are shown as separate rows below the main table.

Group	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	
Period 1	1																		2
Period 2	3	4												5	6	7	8	9	10
Period 3	11	12												13	14	15	16	17	18
Period 4	19	20												21	22	23	24	25	26
Period 5	27	28												29	30	31	32	33	34
Period 6	35	36												37	38	39	40	41	42
Period 7	43	44												45	46	47	48	49	50
Lanthanide Series	51	52	53	54	55	56	57	58	59	60	61	62	63	64	65	66	67	68	69
Actinide Series	70	71	72	73	74	75	76	77	78	79	80	81	82	83	84	85	86	87	88

Fig. 2. Periodic Table of Elements [48]

The basic concept for the Element Solitaire© game is to combine the mechanics of the card game Solitaire with the form and appearance of the periodic table. The player has a deck of cards which contains one card for each element on the table. The cards are drawn at random, one card at a time, and the player must place them in the correct position on the periodic table. If they place the cards incorrectly, the player's score is penalized, and the card is randomly shuffled back into the deck. Some of the solitaire core mechanics have been removed to accommodate the educational bent of the serious game. For example, unlike normal solitaire, there is no concern for matching any sort of card suit to previously placed cards. The player also must place the card, whereas in solitaire the player has the option of simply dealing a new card. To some extent the

mechanics of the game had to be modified to create a more direct correlation between player skill and game performance. Solitaire is notorious in that some of the randomly determined starting states may be impossible to win, which would be undesirable in a serious game.

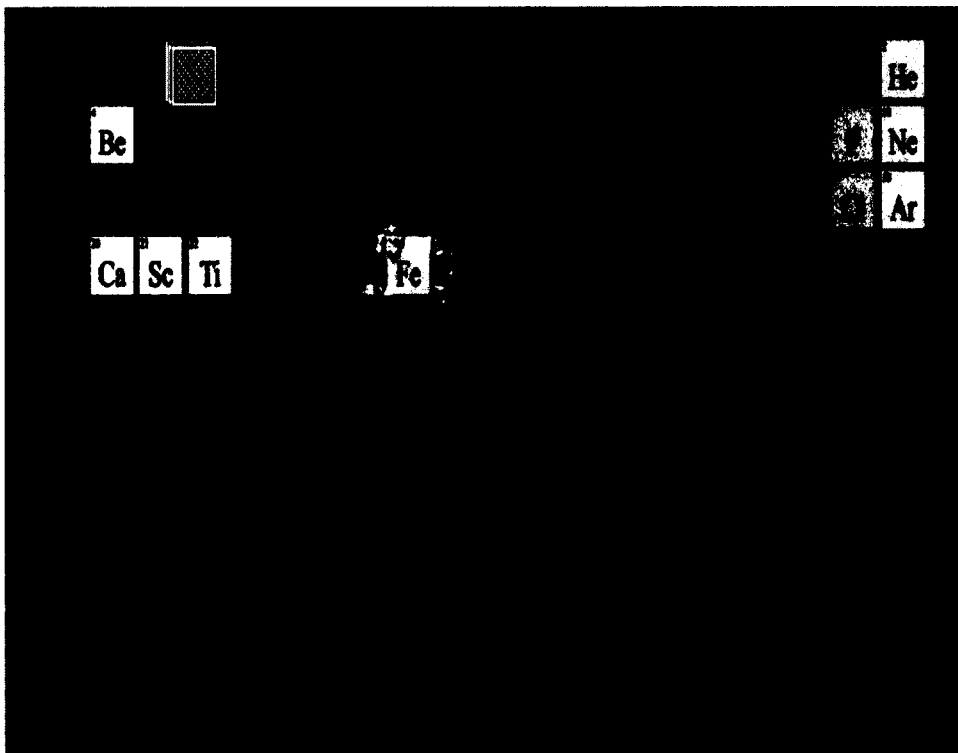


Fig. 3. A Screenshot from Element Solitaire

Rote memorization of the placement of elements in the periodic table, in its own right, is not specifically a learning standard emphasized by many curricula. Instead, Chemistry curricula tend to focus on understanding the relationships between the structure of atoms and their placement on the periodic table [49]. While this makes the game less useful in this form for actual instructional purposes, it does make it well suited for experimentation purposes because it reduces the influence of confounding

instructional factors. Since the specific learning content addressed in the game is not typically emphasized in course curricula, there is a reduced potential that learning outcomes measured in student usage of the game will be a result of external factors. Indeed, initial research with the game, involving both undergraduate level chemistry majors and chemistry faculty, revealed that even these expert level learners did not have mastery of periodic table memorization.

Because of the nature of this game, the most obvious obstacle preventing it from fulfilling all the synthetic propositions is the lack of meaningful choice. In many ways, the game is effectively a graphical implementation of a fill-in-the-blank style quiz. As mentioned, the initial design choice was made to force the player to place each element before drawing a new one. As a result, early iterations of the game precluded any meaningful choice. As the players were given elements, they either placed them correctly, or they were penalized for failing to do so. Though the program had a graphic interface and the elements had an appearance of playing cards, the limited nature of the game meant that there was no conceptual space to explore. The program simply presented the user with quiz questions disguised in game graphics. Though different in execution, this program, in spirit, resembled many of the aforementioned online quizzes. In order to add more decision space to explore, four game artifacts were added to provide the user with more meaningful choices.

Foremost is that an abstract scoring mechanic was added to the game. This system rewards the player with a specified amount of points for each element correctly placed, and deducts an amount for incorrect placements. Additionally, not only do players get rewarded for correct answers, but they also increase a score multiplier, which

links their decisions on how they choose to answer questions with the rewards they can receive on future correct answers. As they score better, their multiplier increases, allowing them to score even higher on subsequent correct placements. This factor also adds significance to the decision the player must make in balancing the risk and reward of placing the elements. It adds a greater penalty to missing a card, because that mistake not only affects the current card, but through the multiplier, the subsequent cards as well. The intent is to motivate the player to more carefully consider their knowledge of the element placement.

Next, players were given ten 'skips,' so if they wanted to delay placing an element, they had the ability to do so ten times, without penalty. This gives the player a small degree of control in choosing whether to place an element or not. It also adds a measure of strategic depth, as players must ration their skip choices, and forcing them to weigh the risk of skipping a present element versus the need to be able to skip an element later on.

Third, when placing an element, the players are given a countdown timer. Players are awarded a time bonus if they place the cards before the countdown timer expires. This motivates the player to rapidly decide where to place the card, and becomes especially important for players seeking to achieve the highest score possible. The time bonus is the number of seconds remaining when the player places the card, so every second matters.

Lastly, the players are provided with the opportunity to use hints. The players have the opportunity to trade off some of the points they might score for the information gained by using a hint. These hints progressively reveal the cards family name, the

associated color for the periodic table, and finally the location of the element. Each hint level costs the player a higher penalty in terms of points. The penalty for using the hints is that the score the player receives for placing a card decreases as more hints are used, until, ultimately, no points are awarded if the card's correct position is shown to the player. A player can also choose to capitalize on this, if they are willing to accept a lower reward. Again, this mechanic allows the player decide how to balance risk and reward. As risk diminishes, so does the reward.

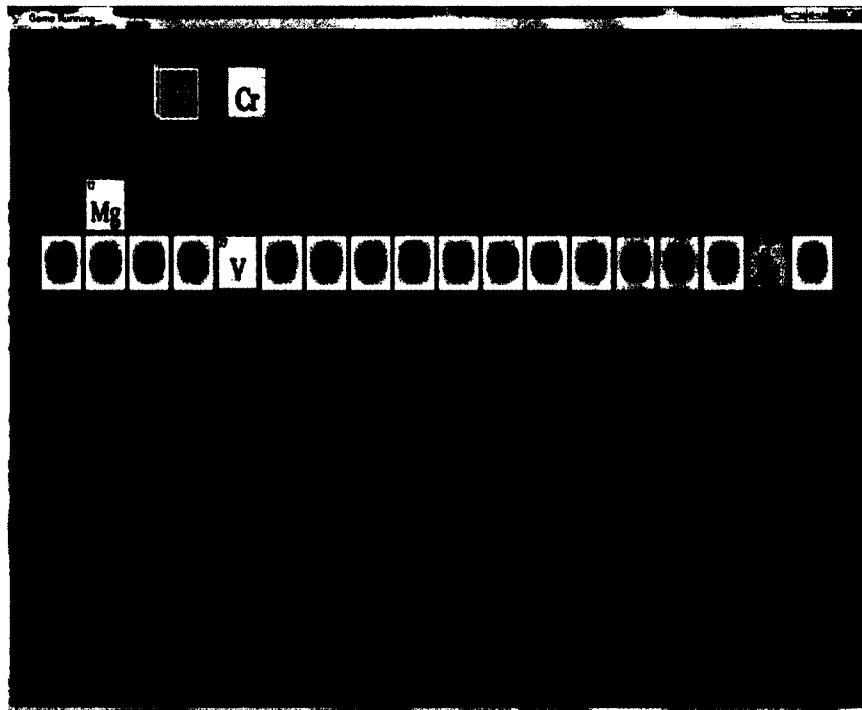


Fig. 4. Hint Being Shown in Element Solitaire

These four mechanics of the game combine to create a decision space for the player to explore, and extend the game space beyond simply entering a right or wrong answer. These factors do not possess the depth nor the scale of the types of decision often made in a highly strategic game, such as Sid Meier's Civilization games, but they

do create a small space for the learner to explore. With an array of possible actions, the player can play how they like, and, as described by game designer Chris Crawford, imprint their own personality on the game [17]. Fig. 4 shows a screenshot from a game in play, with a hint showing the family and row of the element.

Another useful feature in the game is that the game itself is a client application, which uploads data from the player's performance to a remote server. This data is collected while the user is playing, and contains a robust collection of information, including how long each session took, the user's score, the number of hints and skips used and the elements which were missed. A sample of the data collected on the server can be seen in APPENDIX E. This data collection mechanism proved very useful for facilitating research with the game, and provided insight into exactly how the player are using the various features.

During the course of this research, the automated data collection aspect of the game was expanded upon to handle the administrative overhead associated with experimental research design, especially experimental research involving volunteer participants. The downloadable client program was added upon to include an administrative "wrapper" program around the Element Solitaire© game. This "wrapper" program, entitled Testing and Experiment Platform (TEP), was designed to encapsulate the experimental design and administration into an application which the participants could use at their own convenience. Providing this testing platform alleviated some of the practical barriers to student participation in a relatively time consuming, voluntary experiment. Without this administrative "wrapper," the research administrators would have had to coordinate times and locations for the participants to meet in order complete

the experiment requirements. Such mandates and requirements would likely have created significant barriers to volunteer participation, especially when dealing with a weeklong experiment that required multiple, distinct efforts. The TEP wrapper, however, allowed the volunteers to participate in the experiment at their own convenience, from their own computers, whenever and wherever they liked, within certain loose experimental parameters.

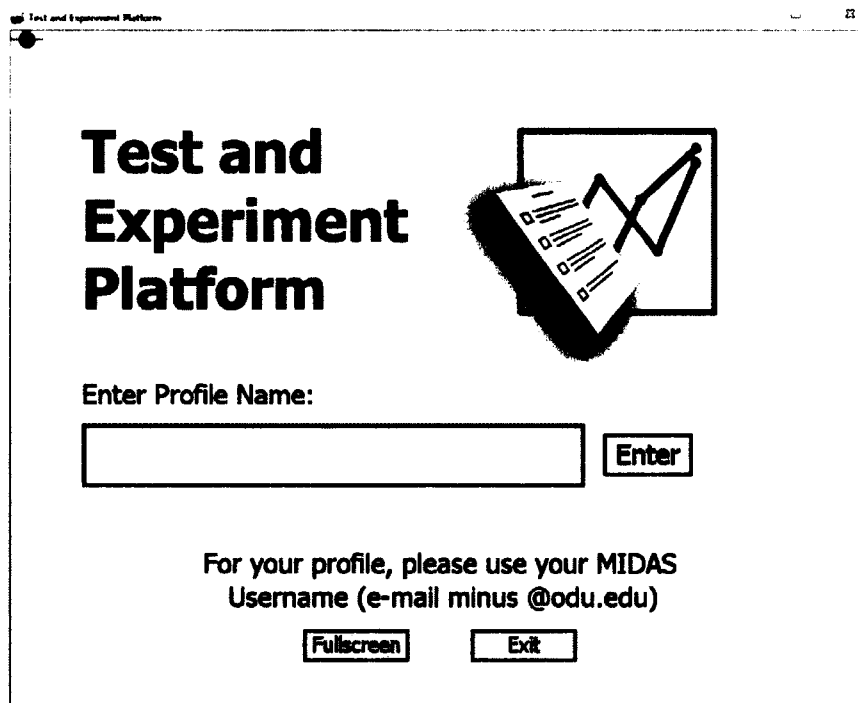


Fig. 5. TEP Title Screen

When a participant first used the TEP program, they were prompted to enter a unique username. The program then administers the research consent form to the participants and provides them with an overview of the study, as well as some basic instructions.

Test and Experiment Platform 24

Experiment Participation Consent Form

I hereby agree to participate as a volunteer in the TEP Research Project. I know that I will be asked to interact with this TEP computer program in the course of this research project. Following the conclusion of the study I will have the opportunity to obtain an explanation of the study and its purposes.

I understand that participation in this study will require approximately between 0.5 and 1 total cumulative hours over a period of one week.

I understand that a record of TEP performance results will be collected in this study, and that these results will be kept confidential, within the limits of the law.

I understand that digital records of my performance may be analyzed by other credible researchers. However, no personal identifying information will be preserved or associated with performance data collected in this study.

Back **Continue**

Fig. 6. Interactive Research Consent Form

Participants were then given a pre-test, in which they were asked to enter in the symbol names for as many of the 118 chemical elements as they can remember. When this pre-test was complete, the pre-test score and username were stored on a network server, and the participant's unique username is registered. After a participant was registered, the network server assigned the participant to a treatment group. Each time a user logged on, the game client requested a username validation from the server. In the validation response from the server, the client received the proper treatment assignment every time the user played the game. Treatment assignments were incremented with each participant, ensuring that each treatment group never varied in population by more than one.

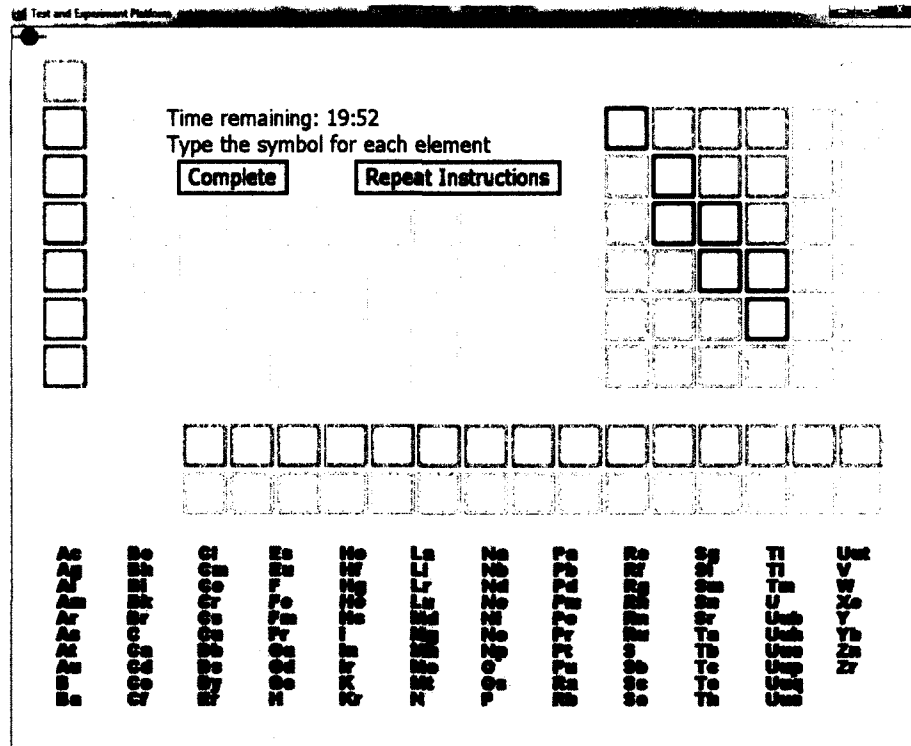


Fig. 7. Pre-Test

Based on the treatment assigned by the server, the TEP client then provided the participants with access to the variant of the Element Solitaire© serious game intervention appropriate to their treatment group. The end result was intended to make the treatment assignments opaque to the participants. Whenever the participants played the serious game, detailed records of their gameplay sessions were automatically reported to the server. These records include such information as a date-time stamp for when a game was started, what kind of game was played, how long the participant played the game, what score they received, whether they completed the game, what elements they missed, and how many hints or skips they used.

3.2 Pilot Study

In February of 2011, a pilot study was conducted with the Element Solitaire software. The primary purpose was usability and load testing of the Element Solitaire© client and server software. The secondary purpose was to test the experiment format and gain a preliminary indication of the viability of this line of inquiry. The results appear to be positive for both purposes.

The study involved thirteen members of the Old Dominion University Chapter of the American Chemical Society. Eleven of the participants were undergraduate students, and two were professors. Before the participants played the game, they were asked to take a pre-test to assess how well they knew the periodic table. The pretest can be seen in APPENDIX A. These volunteers were then given access to Element Solitaire© for one week. It is important to note that the pilot study was conducted prior to the TEP additions to the software. During this time, they were asked to play the game a minimum of two times. At the completion of the study, the participants took a post-test, identical to the pre-test, and they completed the survey in APPENDIX B. The results of the survey are shown in Table 1, and the data collected from the server is shown in Table 2.

3.2.1 Pilot Study Outcome

The pre-test confirmed an interesting aspect of the subject matter: even though the study participants might be considered at between intermediate and experts learners in the field of Chemistry, the group average for correctly placed element symbols in the pre-test was only 13%. This alleviated fears of an initial “ceiling” effect which would confound the learning outcomes of the game. In discussions with the participants, subject matter experts, and consultation of curricula standards, it became apparent that memorization of

the periodic table is not a highly emphasized learning goal. As mentioned previously, this makes the learning content well suited for experimentation.

Table 1. Pilot Study Pre/Post Test and Survey Results

	Pre Test			Post Test			Pre/Post Difference	Age	Gender	Installed on own comp	Degree	Program	Year	Video Game Freq	Video Game Hours Per Week	Gamer
	Correct	Wrong	Blank	Correct	Wrong	Blank										
1	3	13	20	36	0	0	33		Yes			Biology	4	Less Than Monthly	0	Not At All
2	26	10	0	34	2	0	8		Yes				3	Weekly	3	Somewhat
3	18	2	16	36	0	0	18		Yes			Chemistry	3	Never	0	Not At All
4	8	2	26	36	0	0	28		Yes			Chemistry	4	Less Than Monthly	0	Not At All
5	29	4	3	36	0	0	7		Yes				3	Daily	12	Somewhat
6	14	18	4	31	2	3	17		Yes			Bio-Chem	3	Daily	20	Very Much So
7	10	4	22	27	1	8	17		Yes			Bio-Chem	3	Weekly	3	
8	10	3	23	12	4	20	2		Yes				2	Less Than Monthly	0	Not Really
9	10	1	25	19	0	17	9		No			Chemistry	3	Weekly	6	Somewhat
10	8	5	23	7	6	25	-1		Yes			Bio-Chem	3	Daily	10	Somewhat
11	19	4	13													
12	6	12	18													
13	11	0	25													
All	13.23 37%			31.00 86%												
Played				13.00 36%												
Didn't Play																

Table 1. Continued

Survey										
Competitive	Look at Scoreboard	Recognize Other on the Scoreboard	Try to Outscore others?	Times Played	Score is a result of knowledge	Possible to score high without knowledge	Usability	Difficulty for you	Difficulty for Chemistry Novice	External Material Use (Cheat Sheet)
1 Very Much So	Yes	Yes	Yes	12	Agree	Disagree	Easy	Just Right	Somewhat Hard	No
2 Very Much So	Yes	Yes	Yes	4	Strongly Agree	Strongly Disagree	Easy	Just Right	Just Right	No
3 Not Really	Yes	Yes	Yes	15	Agree	Agree	Easy	Just Right	Somewhat Hard	No
4 Very Much So	Yes	Yes	Yes	8	Agree	Agree	Easy	Somewhat Easy	Just Right	No
5 Very Much So	Yes	Yes	Yes	2	Agree	Disagree	A little confusing	Too Easy	Somewhat Hard	No
6 Somewhat	Yes	Yes	Yes	3	Strongly Agree	Disagree	A little confusing	Just Right	Somewhat Hard	No
7 Somewhat	Yes	Yes	No	1	Strongly Agree	Somewhat Agree	A little confusing	Somewhat Hard	Somewhat Hard	No
8 Not Really	No			2	Strongly Agree	Strongly Disagree	Easy	Somewhat Hard	Too Hard	No
9 Somewhat				0						
10 Not Really				0						
11										
12										
13										
					1.5	3.625	1.375	2.875	3.875	
					1 is Desired	5 is Desired	1 is Desired	3 is Desired	3 is Desired	

Table 2. Participant Data from Server

Participant	Total Number of Games	Average Time Playing	Completed Games	Renegs	Highest Score	Ave Hints Used	Ave Skips Used
1	68	00:42.8	19	49	21740	0	0.750
2	7	01:45.0	7	0	21932	0	0.000
3	5	01:59.8	5	0	20850	0	0.200
4	11	02:01.7	11	0	15910	0	0.091
5	9	00:33.3	3	6	21692	0	0.000
Unknown	13	01:06.3	8	5	21932	0	0.461

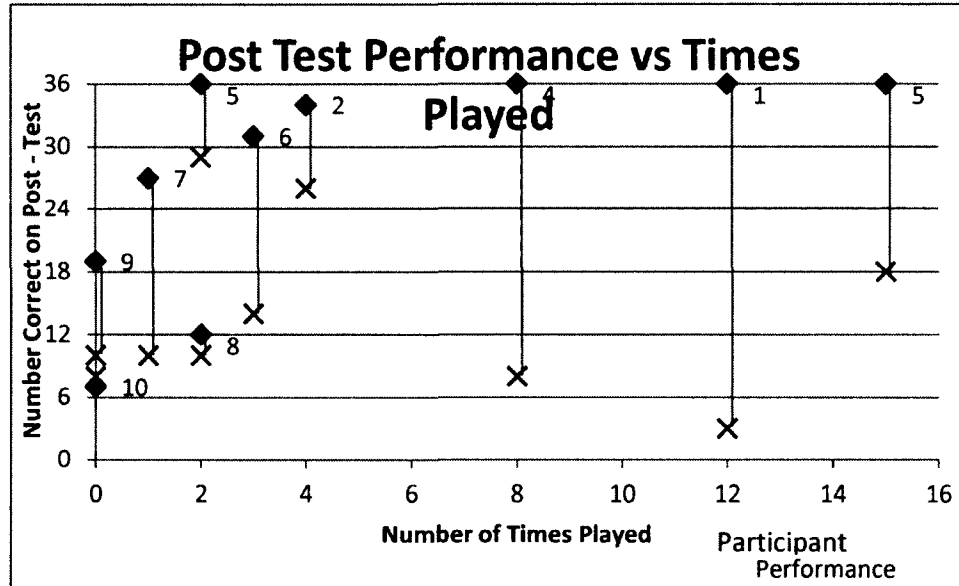


Fig. 8. Pilot Study Post Experiment Performance

During the study, three participants did not complete their participant requirements and were not available to take the post test or survey. Two additional participants did not play the game. Though the study certainly does not have the number of participants to generalize any meaningful conclusions and lacked separate treatments for comparison, the subjects, in effect, self selected their independent variable according

to how many times they played Element Solitaire©. A plot of the number of times (self reported) each participant played the game versus their score on the post test, shown in Fig. 8, indicates a possible positive correlation, and supports the feasibility of conduct more robust experiments in this format. While there was no ceiling effect for the pre-test, a ceiling effect did become evident in the post-test. This effect (with participants scores the highest possible score) hinders the meaningful analysis of the difference between their pre- and post-test performance. There does appear to be a potential relationship between the difference in pre- and post-test performance and the number of times played, but, again, meaningful analysis which might allow conclusions regarding causality would be more valid if the ceiling effect were reduced.

In order to alleviate the detrimental ceiling effect upon the analysis of the data, the decision was made to raise the number of elements used for the full experiment. In the pilot study, the game used only the first thirty-six out of a total of one-hundred and eighteen elements. Programmatically, it was a short matter of work to raise the number of elements available to the user. However, especially with novice learners, there was a risk of overwhelming the user. To improve the game flow for novice learners while still raising the number of elements available to them, a new game mode was incorporated into the game in which the user was dealt only one row of elements at a time. The advantage of this format is that it provides additional scaffolding for novice learners, but doesn't artificially restrict their learning content. In fact, their performance dictates the pace at which they are exposed to new content. The end results was that the Element Solitaire© game has both modes of gameplay available to the user; an Escalation mode and a Challenge mode. In the Escalation mode, as described above, the learner is only

dealing with one row of elements at a time. In Challenge mode, they can select the number of elements they wish to challenge themselves with, and have random access to all of them at once. In order to incentivize the learners to graduate to the Challenge mode, and to compensate for the benefits of scaffolding in the Escalation games, the scores for the Challenge mode are doubled.

3.2.2 Pilot Study Data Collection

The Element Solitaire© client and server software performed well for the pilot studies, and for the most part data collection went smoothly. However, there are a few issues uncovered during the pilot study which will be addressed before future experiments.

Overall, the self reporting of games played was relatively consistent with the data collected from the server. In almost all case, mismatches reflected an under-reporting, rather than over-reporting, which seems to diminish validity threats to the survey data resulting from social desirability response influence. However, it was apparent that a stricter distinction needed to be made between completed and started games. Participant 1 best illustrates this issue in Fig. 8 above. Their survey data reflects twelve self reported game sessions, but their server data reflects nineteen completed games and forty-nine additional “renegs.” The discrepancy between twelve and nineteen reported game sessions is not as big a concern as the renegs. A reneg is a game which is started and not completed. It is possible to speculate that the participant was trying to score very high, and reached a point in their game play when they would renege on a game if they made a mistake. In other words, if they messed up and hurt their score, they would quit the game

and start again. However, without more robust data collection mechanisms, it was hard to do more than speculate. The renegs also dilute the average time spent playing the game, as the data collection in the pilot study reported renegs as having a play time of 0 seconds.

During the pilot study, the server simply recorded a renege as an empty data entry. A blank data entry is created whenever a game is started, and contains only a starting time stamp and the user's name. Once the game is complete, the remaining the performance data, such as score, elements missed, time elapsed, etc is added to the entry. An example of collected performance data on a complete game can be seen in Appendix C. As such, the only information about a renege was who created it and what time the renege game was started.

For the full experiment, the communication protocols between the client and server was updated to address this issue. Additional "reporting" triggers were included to create more robust reporting for the games throughout their play. Specifically, triggers were included so that if an existing game was in progress, and the user opted to quit the program or start a new game, a renege report was generated, sending a timestamp along with available game data to let the server know when the renege occurred. These updates provided additional information to help better understand how the users are interacting with the software.

There was an additional concern with the number of misidentified player entries. Thirteen games data entries had an unknown attribution, and three participants had no data attributed to them on the server. Discussions with the participants revealed that some had simply forgotten to enter their user ID when playing, or had played on a

friend's computer, possibly resulting in a game being misattributed to a study participant. Partly this is a result of the volunteer atmosphere of the pilot study, and it is reasonable to assume that a more formal experiment atmosphere will reduce these discrepancies.

However, the client software itself currently permits users to play as a 'Guest.' For the full experiment, a more robust login mechanism was created, which eliminated the ability to play the game without explicitly entering a unique user ID. Additionally, the expansion of the TEP aspect of the client program made the use of distinct IDs for each user a more prominent aspect for the game architecture as well as for the participants.

3.2.3 Pilot Study Conclusion

Overall, the pilot study results were very encouraging, and indicated that there is a strong potential to observe learning outcomes as a result of using the Element Solitaire© serious game. The study revealed some technical and experiment design issues that were subsequently addressed with prior to conducting the full experiment.

3.3 Design, Variables and Treatments of the Full Experiment

After the updates and changes from the pilot study were made to the software, and the TEP wrapper was fully developed, the full experiment was conducted using randomized controlled trials with five separate experimental groups. Experiment participants were randomly assigned to the treatment groups via the TEP / server structure. The experiment used a pre-/ post-test design. The dependent variable was the difference in the participants' pre- and post-test scores. This difference was defined as

the measure of learning outcome. The treatment groups are derived from the hypotheses from Chapter 2. The hypotheses are:

1. *A serious game with added aesthetic features, to include graphics and music, will be more intrinsically compelling and result in higher learning outcomes than an identical one without music and graphics.*
2. *A serious game with meaningful choices will result in higher learning outcomes than an identical game without meaningful choices.*
3. *A serious game with competition will be more intrinsically compelling and result in higher learning outcomes than an identical one without competition.*

These hypotheses, in turn, were directly translated into experimental conditions. The first condition was the presence and quality of aesthetic effects within the game. For Element Solitaire©, this includes enhanced graphical presentation, as well as additional aesthetic effects such as sound effects, music, card animation, and “sparkle” particle effects. Figs. 9, 10, 11 and 12, on the following pages, provide comparisons of the graphical differences in this condition. However, it is important to emphasize that the difference in aesthetic presentation went beyond static graphics, and included not only animation, but also sound effects and music. Care was taken, however, to ensure that the same learning content is presented in each condition.



Fig. 9. High Aesthetic Presentation

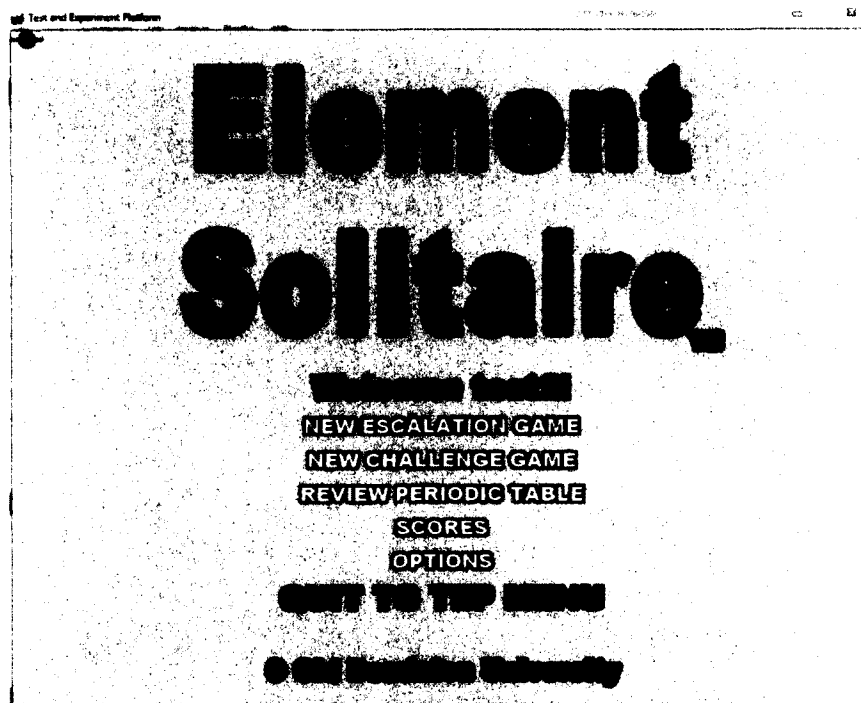


Fig. 10. Low Aesthetic Presentation



Fig. 11. High Aesthetic Game Condition

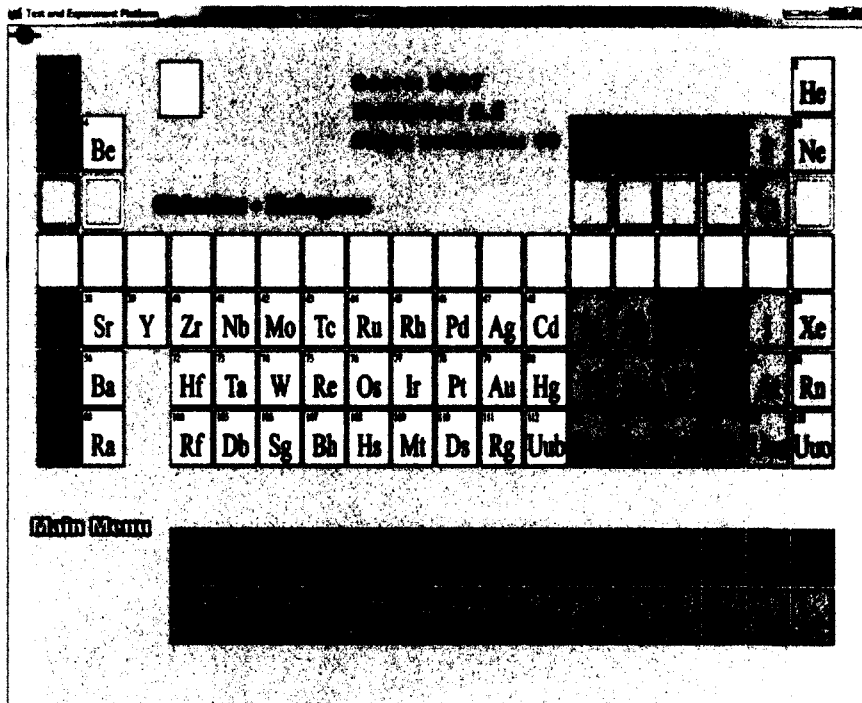


Fig. 12. Low Aesthetic Game Condition

The second condition was the presence of specific choices within the game. These choices were made of two specific options available to the player – the “hint” and the “skip.” The learner had a budget of ten “skips” they can use to delay having to place an element which they might be unsure of. The “hint” gave the learner the option to “purchase” hints for a small score penalty. These hints provided the player information needed to correctly place an element, but diminished the score which they receive when they ultimately place the element correctly. In treatments without these choices, the hint and skip buttons simply did not appear.

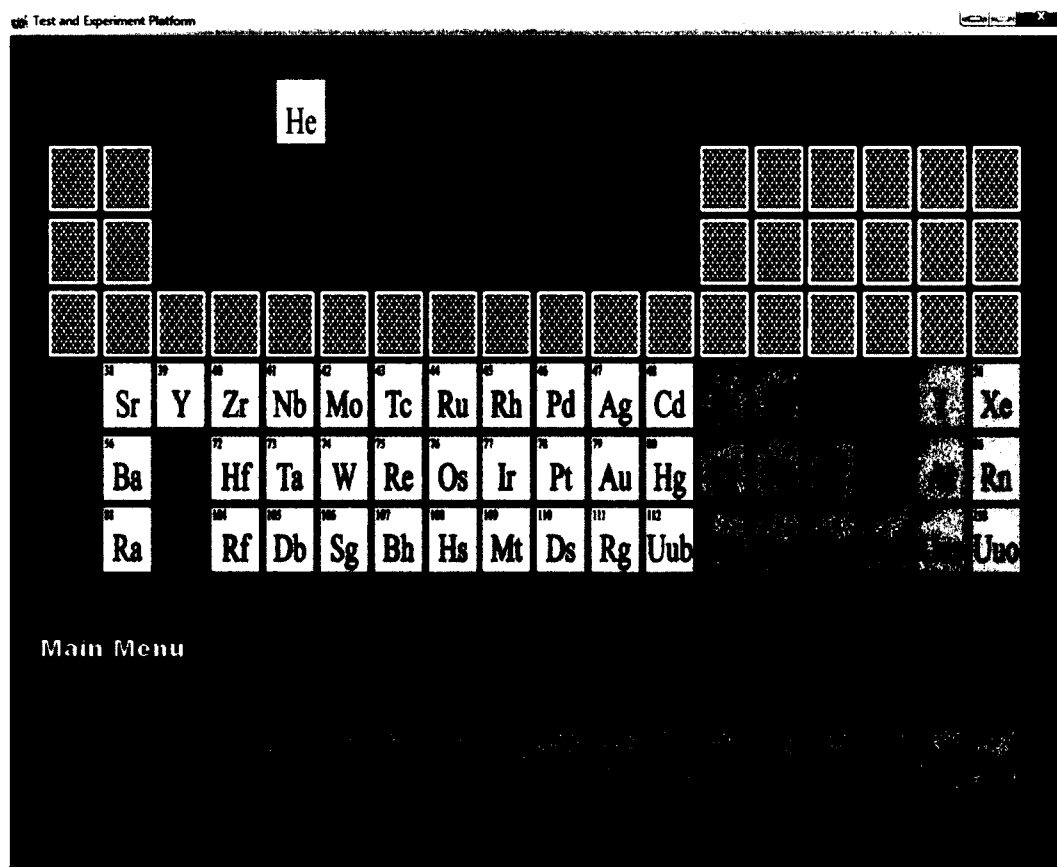
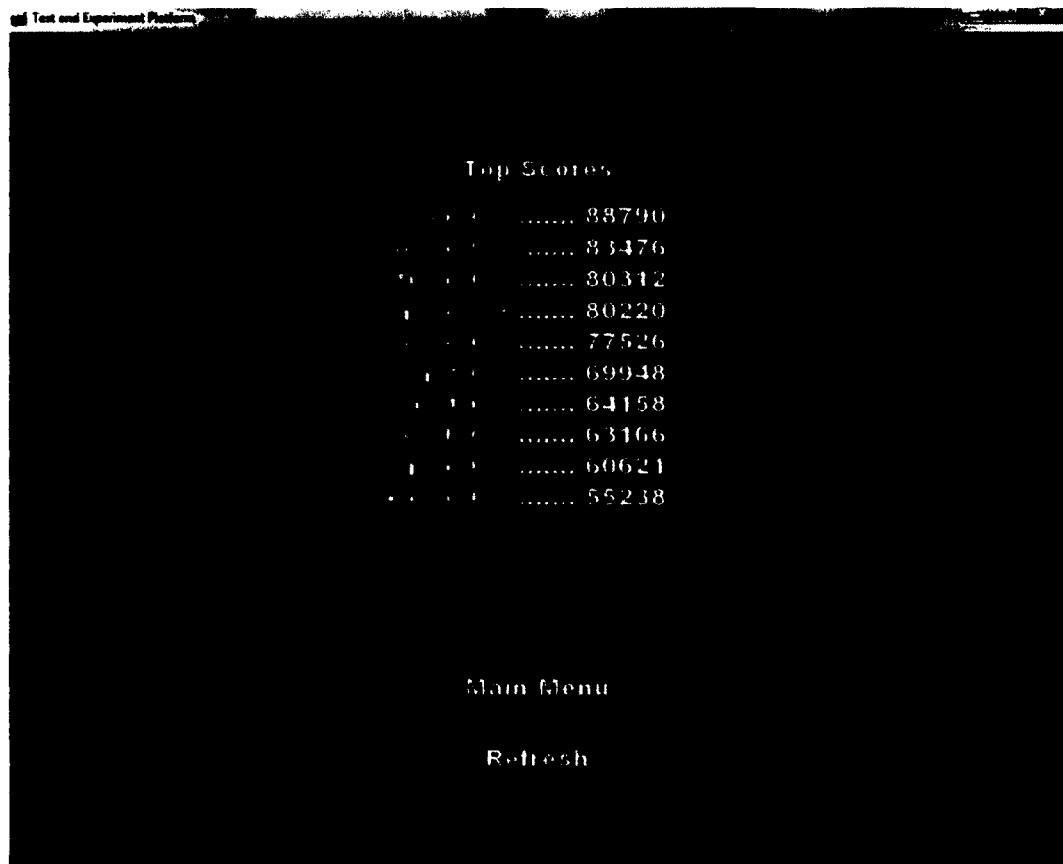


Fig. 13. Game Showing the Hint and Skip Buttons

The third condition was the presence of a network enabled score board. The network scoreboard allowed the player to see what is commonly referred to in the entertainment software industry as a “leaderboard”. This leaderboard listed the names and scores of the top ten players. This is slightly different from a more direct scoreboard, as each player may only have one entry on the board, marking their highest score. Players without this “competition” condition were only shown their own scores, in a traditional scoreboard fashion. Figures 14 and 15 show the difference in the scoreboards between the two condition levels. Note that for privacy purposes, the usernames in these pictures have been intentionally blurred out.



Top Scores	
.....	38790
.....	33476
.....	30312
.....	30220
.....	77526
.....	69948
.....	64158
.....	63166
.....	60621
.....	55238

Main Menu

Refresh

Fig. 14. Scoreboard with the Competition Condition

Top Scores			
.....	2 10 2012	.....	11904
.....	2 10 2012	.....	7621
.....	2 10 2012	.....	3423
.....	2 10 2012	.....	3071
.....	2 10 2012	.....	3016
.....	2 10 2012	.....	1631
.....	2 10 2012	.....	614

Main Menu

Refresh

Fig. 15. Scoreboard with the No Competition Condition

Five experimental groups were used to test these three conditions. The first group was a control group. Participants in the control group took the pre- and post-test, but did not have access to the game. The control group was included to measure the learning effect which might take place due to cueing resulting from the act of taking the pre-test. The performance of the control test was used as the measure against which to compare to ensure that a learning effect did take place, for verification purposes.

The second group was the Baseline game group. This group played Element Solitaire© with all three conditions present. The game featured the full aesthetic presentation, the full breadth of available gameplay choices, and the networked leaderboard. This version of Element Solitaire© was considered to be the standard

version of the game, and this treatment groups served as the baseline from which to compare the performance of the other experimental treatments. The Baseline performance served as the yardstick against which the other experimental groups were compared. According to the hypotheses, the difference between the Baseline group's pre- and post-test scores should be higher than the difference for any other group.

These remaining experimental treatments were reductive iterations of this baseline treatment. The second treatment retained the "choices" and "score board" conditions, and omitted the "aesthetics" condition. The third treatment retained the "choices" and "aesthetics" conditions, but omitted the "score board" condition. The fourth and final treatment omitted the "choices" condition, while retaining the "score board" and "aesthetics" conditions. The control group effectively omitted all conditions by not being exposed to the game. The Group-to-Condition interaction is shown in Table 3.

Table 3. Group to Condition Interactions

Group to Condition Interactions

Group \ Condition	Aesthetics	Choice	Competition (Score Board)
Control Group	-	-	-
Baseline	X	X	X
Diminished Aesthetics	-	X	X
Diminished Choices	X	-	X
No Competition	X	X	-

- denotes absence of condition
X denotes presence of condition

All treatment groups took a pre-test, were asked to play Element Solitaire© four times (excluding the Control Group). After one week, and after the individual player had completed a minimum of four games, they were asked to take the post-test as a means of assessing their learning outcomes. The TEP software wrapper ensured that the individual user was not allowed to take the pre-test unless the server reported that they had the sufficient number of complete games recorded, and that the appropriate amount of time had passed.

In accordance with the IRB standards, and for the protection of the participants, all personal identifying data, such as username, were stripped from the experiment data once the experiment was complete. During the experiment, all participants used their ODU e-mail account name as their usernames. Using these familiar usernames ensured that each participant would have a unique name, prevent misattribution of experiment performance. For treatments in the second experiment (involving competition), the usernames were also a significant factor related to how a sense of competition is engendered via the use of the score board. Because of the familiarity of the usernames structure, experiment participants would be able to recognize each other on the scoreboard, while playing the game.

3.4 Research Participants

The research participants were drawn from the Old Dominion University Chemistry Department. Specifically, the participants were all students in the CHEM 123 Foundations of Chemistry course. This course is described as a core requirement for science and engineering majors, and is intended to prepare students for subsequent

studies in molecular science[50]. The students taking this course were primarily freshmen or sophomores in their undergraduate studies, and were typically between 18 and 23 years old. This particular demographic was chosen to increase the probability that the participants would be novices with regards to the learning content covered by the serious game interventions, but that they would still have a sufficient threshold level of interest in the subject matter.

The invitation to voluntarily participate in the program was given to two sections of this course, each taught by different instructors. The two classes had a total of 533 students. From these potential participants, 235 registered to participate in the experiment. 172 of the participants actually completed the experiment. It should be reiterated that the experiment was relatively intensive in terms of required effort. In order to complete the experiment, the participants had to take a pre-test on the periodic table of elements, play the game a minimum of four times, and then take the post-test. The estimated combined total time commitment is estimated at approximately one hour, over the course of one week.

3.5 Measures

The measure of dependent variable was collected via the pre- and post- tests administered to the study participants through the TEP wrapper program. The dependent variable was defined specifically as the difference between the post-test score (the number of correctly placed element symbols) and the pre-test score. In other words, the dependent variable will be the amount by which the post-test score increases from the pre-test score. This should indicate how much the participants learned between the pre-

and post-test, which in turn, should indicate the learning outcome associated with the respective condition associated with each participant's experiment group.

Care was taken in formulating the pre- and post-tests to ensure that there was a very high degree of congruency between the learning content as presented within the game and the learning content as tested in the pre- and post-test. The presentation for the pre- and post-test was designed to ensure that the same cues were available to the learners as was available to them in the game. The blank periodic table with family color coding was presented, along with a listing of the symbol names at the bottom of the screen Fig. 7). Due to the automated nature of the data collection, the measures are presumed to have a high degree of reliability. There were not any server errors or inconsistent data that would indicate otherwise.

The network protocol between the server and client applications were designed to withstand network failures or unexpected shutdowns of the software. If some interruption prevented the user from being able to communicate with the server, the data was stored locally on the user's computer until it can be uploaded.

Similarly, the data will have a high degree of validity because it exactly records how often the user plays the game. The data is stored according to the user's name, and one threat to the validity and reliability of the data is if the user fails to consistently use the proper name.

The only threat to the data integrity might have been if a participant cheated or allowed someone else to play the game for them, or plays the game on another computer but forgot to log in as their assigned name. The possibility that a participant would cheat or allow someone else to play is an uncontrollable variable that cannot be prevented

unless the participants were required participate in a controlled setting, such as a computer lab. However, doing so over such an extended period of time would have like had a significant detrimental impact upon the rate of volunteer participation.

CHAPTER 4

EXPERIMENT RESULTS AND ANALYSIS

This chapter presents the results of the experiment and the analysis of the raw data. The analytic test used (the t-test) is described and applied to the data, and the results are then interpreted in terms of the original hypotheses. The chapter concludes with a discussion of the implications of the results; both those that supported the hypotheses and those that did not.

4.1 Results

At the conclusion of the experiment, 172 of the original 235 participants completed all of the requirements. While the original apportionment of participants to experimental groups was tightly controlled, the attrition rate in each group varied, leaving each experimental group with different number of observations points. The participation goal was to have 40 participants in each experimental group. The actual results fell slightly short of this goal. However, the number of samples in each treatment still provides a sufficient number of measures for statistical analysis. Table 4 shows the number of participants that completed the experiment, broken down by experimental group.

Table 4. Total Number of Completed Participants

Completed Samples Per Treatment	
Total	172
Control	38
Baseline	32
Degraded Aesthetics	29
Degraded Choices	36
No Competition	37

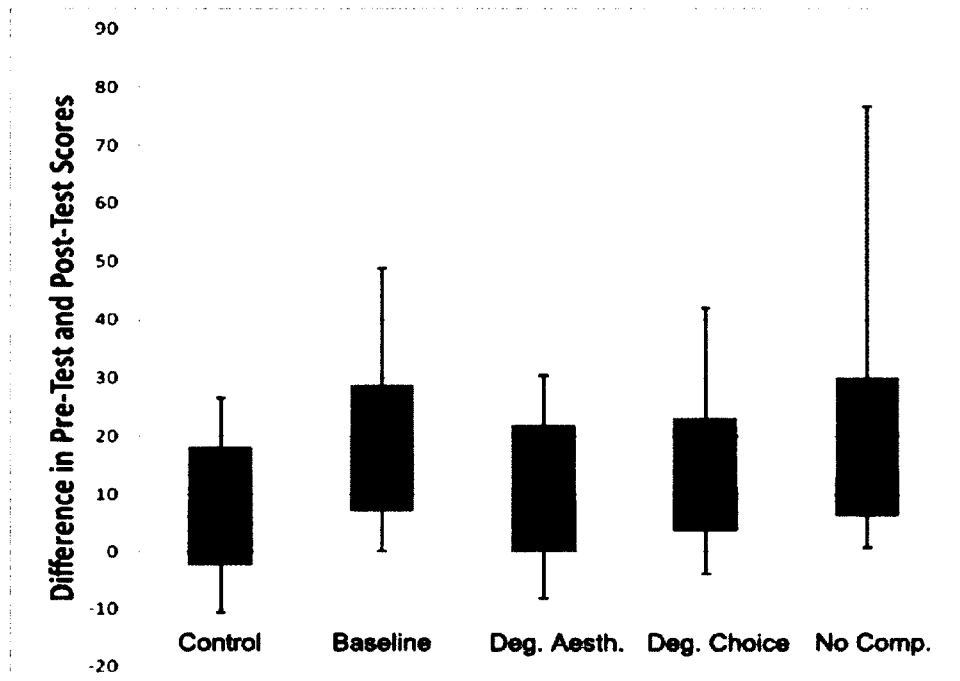


Fig. 16. Boxplot for the Measures of Learning Outcome, Grouped by Treatment

Fig. 16 shows the boxplots of the differences between each participant's pre-test and post-test score, as grouped by treatment. For these boxplots, the red box represents the region of scores between the 25% and 50% percentile. The green box represents the region between the 50% and 75% percentile, and the whiskers represent the respective 10th and 90th percentiles.

Initial inspection of the boxplots indicates that the baseline treatment group had a relatively high positive difference in the pre-test and post-test scores in comparison to all other treatment groups, with the exception of the No Competition group. Even with the No Competition group, the median value in the Baseline group is well below the median value for the Baseline group, as evidenced in Figure 10. Additionally, the No Competition group also seems to have a wider variance in the observed data points, as indicated by the fact that the 75th and 90th percentiles appear to be higher than the

corresponding percentiles for the Baseline group, and yet the 25th percentile appears to be lower than the 25th percentile for the Baseline group.

These observations are supported by inspection of the descriptive statistics presented for each of the experiment groups in Table 5. Beginning with the top row, we see that the Baseline group has a higher median (or middle value from each data set) than any of the other experimental groups. However, when comparing Means (or averages) from each data set, we see that the Mean for the No Competition data set is actually higher than the Mean for the Baseline data set.

Table 5. Descriptive Statistics for the Differences in Pre-Test and Post-Test for Experimental Groups

	<i>Control</i>	<i>Baseline</i>	<i>Deg. Aesth.</i>	<i>Deg. Choice</i>	<i>No Comp.</i>
Median	6.50	19.5	9	11	13
Mean	7.92	20.09	8.90	16.67	23.08
St. Dev.	23.94	21.40	26.96	25.33	30.14
Count	38	32	29	36	37

Standard Deviation, in the 3rd row, indicates the measure of variability in each data set. As expected from the Boxplots in Fig. 16, the variance for the No Competition group is the greatest. Lastly, the final row indicates the number observations in each experiment group. These numbers are the same as in Table 5.

4.2 Analysis

In order to assess the statistical significance of these results, a t-test was selected as a method of statistically comparing the experiment group means, or expected values [51-54]. The t-test is more tolerant of smaller sample sizes than the more common and

more discriminating z-test. The z-test bases the comparison of two population samples on an assumption that the underlying data is normally distributed. In accordance with the Central Limit Theorem, the minimum number of data points desired for a z-test is typically around thirty [53]. Most of the experiment groups did have more than thirty observations, with the exception of the Degraded Aesthetics group. While the significance of there being twenty-nine versus thirty samples may be debatable, the t-test was chosen in the interest of erring on the side of caution. The implication of this test selection is that the results are more conservative, in favor of the null hypothesis, which creates a greater burden of proof. As a result, it also may be interpreted as having a greater degree of confidence in the results.

The basic structure for all of the t-tests is to establish null and alternate hypotheses which correspond with the hypotheses developed in Chapter 2. These hypotheses are:

- 1. A serious game with added aesthetic features, to include graphics and music, will be more intrinsically compelling and result in higher learning outcomes than an identical one without music and graphics.*
- 2. A serious game with meaningful choices will result in higher learning outcomes than an identical game without meaningful choices.*
- 3. A serious game with competition will be more intrinsically compelling and result in higher learning outcomes than an identical one without competition.*

Each of these hypotheses compares the data from the Baseline treatment group with the three experimental treatment groups. As is standard for the t-test, the null hypothesis is that there is no difference between the data sets [53].

$$H_0 = \text{the difference of sample means between treatments} = 0$$

The formalized null hypothesis states that the presence of each specific design principle will not significantly improve learning outcome. Accordingly, the correspondent alternate hypothesis for each condition will be that the baseline sample mean will be higher than the respective mean from the experimental group:

$$H_{O_1} = \text{the difference between the Baseline Mean and the Degraded Aesthetics Mean} = 0$$

$$H_{A_1} = \text{the difference between the Baseline Mean and the Degraded Aesthetics Mean} > 0$$

$$H_{O_2} = \text{the difference between the Baseline Mean and the Degraded Choice Mean} = 0$$

$$H_{A_2} = \text{the difference between the Baseline Mean and the Degraded Choice Mean} > 0$$

$$H_{O_3} = \text{the difference between the Baseline Mean and the No Competition Mean} = 0$$

$$H_{A_3} = \text{the difference between the Baseline Mean and the No Competition Mean} > 0$$

The test statistic for the t-test is called the t-value. It is the calculation of the normalized ratio of the observed value (the mean) in terms of standard error. The t-value is calculated by dividing the difference in the population means by a calculation of the standard error of the differences. This indicates where on the t-distribution curve the

observed t-value sits. The descriptive statistics of the various treatments suggest that the variances might not be the same, so Welch's t-test variant for different population variance is used [55]. The interim t-value for each hypothesis is calculated as:

$$t - value = \frac{\mu_1 - \mu_2}{\sqrt{\frac{s_1^2}{n_1} + \frac{s_2^2}{n_2}}}$$

where:

μ = the sample mean

s = the sample standard deviation

n = the number of observations

The t-value can then be used to calculate a resulting p-value by comparing the t-value to the t-distribution described by the degrees of freedom for the test. The p-values indicate the probability of finding the given observations if the null hypotheses are true. The degrees of freedom are equal to the smallest number of sample observations minus one ($n_{\min} - 1$). Effectively, the p-value is the cumulative probability distribution function of the t-distribution, calculated from negative infinity to the given t-value (for our one sided t-test). This represents the normalized area under the t-distribution curve up to the t-value. The equation for the cumulative probability distribution can be written in terms of I , the regularized incomplete beta function [56]:

$$\int_{-\infty}^t f(u) du = 1 - \frac{1}{2} I_{x(t)} \left(\frac{\nu}{2}, \frac{1}{2} \right)$$

where

$$x(t) = \frac{v}{t^2 + v}$$

and v is the number of degrees of freedom.

The actual calculation of this percentage value involves a relatively complicated integration of the distribution, and is beyond the scope of this research. Fortunately, many statistical references include sample t-value tables, which allow an analyst to describe a range for the actual p-value by simply looking up bracketing t-values [51-54]. Additionally, many popular statistical analysis software solutions provide computational methods for directly determining a p-value, which allows a more accurate assessment of the p-value. For this analysis, the p-value calculation was performed via the Vassar Statistical Tables Calculator website [57].

Table 6. T-test and P-value Results for Mean Comparisons between Experimental Groups

T-tests and Resultant P-Values

Test	Baseline – Deg. Aesth.	Baseline – Deg. Choice	Baseline – No Comp.	Baseline – Control	Deg. Aesth. – Control
P-Value	0.0426	0.2749	0.3176	0.016	0.4394
Result	Significant – Reject H_0	Not Significant – Cannot Reject H_0	Not Significant – Cannot Reject H_0	Significant – Reject H_0	Not Significant – Cannot Reject H_0

H_0 : The difference between treatments = 0

H_A : The difference between treatments > 0

Critical α -value of 0.05

Table 6 shows the t-test results for five comparisons of the treatment means. The means being compared are listed in the top row. A critical value (α) of 0.05 was selected as the maximum p-value acceptable for rejection of a null hypothesis.

These tests indicate that there was a statistically significant difference between the learning outcomes of the Baseline and the Degraded Aesthetics experimental groups. In fact, the negative impact of the degraded aesthetics was so substantial that there was no statistical significance between the measured learning outcome of the Degraded Graphics experimental group and the Control group, who did not play the game at all.

The tests do not, however, indicate a statistically significant difference between the Baseline group and the Degraded Choice experimental group or No Competition experimental group. In the case of the No Competition group, cursory examination of the descriptive statistics for each group in Figure 10, as well as their respective boxplots in Figure 9, suggests that in some measures, the No Competition group might actually have perform better than the baseline group.

As a means of comparison, the test of the difference between then Baseline group and the Control group is included, and it does indeed, indicate that the Baseline Group has a statistically significantly higher learning outcome than those who did not play the game.

4.3 Discussion

The following section discusses the findings for each treatment group, as well as the implications for the associated hypothesis.

4.3.1 Aesthetic Presentation

The results of the t-test comparing the Baseline Group and the Degraded Aesthetic Experimental Group do support the hypothesis that aesthetic presentation has an impact on learning outcomes. While the hypothesis predicted such an outcome, the scope of the effect on the learning outcome, to the point where those playing with the degraded graphics did not perform statistically better than those who did not play the game, was surprising. To reemphasize, the last column of Table 6 compares the means of the Control experiment group results, who only took the pre-test and post-test, with the Degraded Graphics experiment group. The t-test indicates that with a p-value of 0.4394, there is insufficient evidence to reject the null hypothesis; in this case the mean change in score between the pre-test and post-test was different. This indicates that playing the game with poor aesthetic presentation is no different than not playing the game. Alternately, this indicates that poor aesthetic presentation has the potential to completely nullify any learning potential present in a serious game.

This surprise conclusion is amplified even more when the examining the number of average games played by each group. The thirty-two Baseline experimental group participants played an average of 5.21 games per participant, and completed an average of 4.15 games. In comparison, the twenty-nine Degraded Aesthetic group participants played an average of 6.23 games, and completed an average of 4.98 games. Upon finding that the Degraded Aesthetics group performed statistically worse than the Baseline group, one might presume that the diminished graphics made the game less appealing, and therefore the participants may have played it less. But the data collected by the server shows that the opposite is true. Those playing the game with the Degraded

Aesthetics condition played the game, on average, more than those in the Baseline group, and yet still performed worse.

Table 7. Comparison of Number of Games Played and Completed

Treatment	Average Games	
	Played	Completed
Baseline	5.21	4.14
Deg Aesth	6.23	4.97

Caution should be taken when comparing these numbers as the experiment design created a significant confounding effect upon the number of games any participant played. Specifically, the participants were told they had to play a minimum of four games. One could imagine scenarios in which this administrative imperative could either artificially inflate or depress the number of games which a participant might play otherwise. However, both experimental groups were subject to this same effect. Bearing this caveat in mind, the difference still suggests that graphics not only improved the learning effect, but possibly made the learning more effective: those with better graphics improved much more with fewer games.

One possible explanation for this result might be a variation on the psychological “halo” effect [58]. The high quality aesthetic presentation might create a positive bias in the mind of the user, prompting them to engage in a more effective and efficient manner with the learning material. In contrast, the low quality aesthetic presentation may cause the user to dismiss the learning content out of hand.

Unfortunately for serious game developers, the practical corollary to this principle is that enhanced graphics tend to cost more and take more time to develop. The

entertainment software industry has been struggling with the burden of ballooning game development budgets, attributable, in large part, to the increased cost of creating high quality assets [2, 44, 45, 59]. The results of this research seem to indicate that serious game developers might have to be concerned with the same challenge of delivering high quality aesthetic presentations to their users as faced by the entertainment industry.

4.3.2 Choice

The statistical analysis of the Degraded Choice experimental group indicates that the treatment had no effect upon the learning outcome. In trying to understand this outcome, it is, again, useful to examine the records of the games played.

In the course of the experiment, 1067 separate games were recorded by the networked server. 789 of these games were played by participants who were not in the Degraded Choice treatment group. In those 789 games, only 3 total “hints” were used. In contrast, 349 “skips” were used.

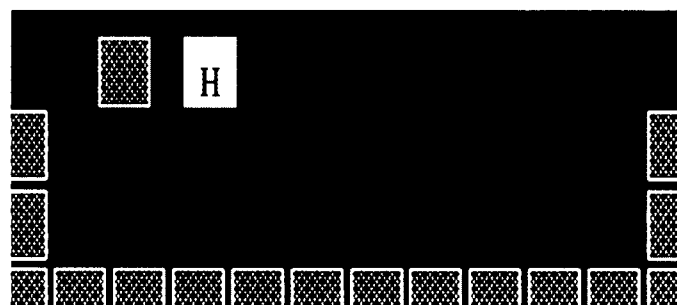


Fig. 17. The Placement of the Hint and Skip Controls

Given the proximity and similarity of the “hint” user interface to the “skip” user interface, as showing in Fig. 17, it seems unlikely that the participants were unaware of

the presence of the hint button. More likely, it seems that the Hint button was never considered a viable or rewarding option to the player.

Schubert, a lead developer at Bioware Corporation, provides insight into the role of player choice in creating entertainment game, and provides tested guidelines for creating “meaningful choices”[60]. Schubert discusses the numerous factors that go into the valuation which a player places upon the choices made available to them within any game. The game designer is responsible for creating viable alternative choices that create high value alternatives for the player. Within this context, it seems likely that the relatively low penalty for failing to place an element (points are deducted) may make the option of getting a hint an unviable and non-meaningful choice.

A possible reformulation of the current game might be to end the game when the player misplaces a specified number of elements. This version of player “death” could incentivize the use of the hint button, and induce the player to consider more carefully their available options. It may be informative to compare this alter game structure which places more emphasis on player choice with the existing, more forgiving game structure to further explore the role of choice in learning.

4.3.3 Competition

As with Choice, the analysis revealed no statistically significant difference between the No Competition and Baseline experimental groups. As discussed in Section IV and demonstrated in Fig. 16 and Table 5, however, the No Competition experiment group exhibits a much wider variance in the performance than any of the other

experimental groups, and its mean value is actually higher than the mean of the Baseline Group.

Possible explanations for this result can be found in educational research on the subject of competition. Educational literature discusses proposed pre-requisites for creating a learning environment conducive to constructive competition, as opposed to destructive competition [61-63]. Constructive competition can enhance learner motivation and performance, while destructive competition can have the opposite effect. Without strict guidance and cues on the nature of the competition, the affective result upon the individual learner depends, in large part, upon how they internalize the competition. Competitive personalities may be motivated by the competitive nature of the game, while non-competitive personalities may become de-motivated. The two divergent responses to the same stimuli could create a potentially bi-modal response.

This may account for the wide variation seen in the No Competition experimental group measurements. While some participants might have perceived the leaderboard as a destructive competitive artifact, the No Competition experimental group was only shown a history of their own scores. In effect, they were only competing with themselves, which, in some cases, may have been perceived as more constructive.

4.4 Experiment Limitations

The following sections discuss the limitations of the experiment, categorized in terms of internal and external validity. The sections include assessments of the impact of these limitations upon the research, as well as efforts to mitigate the impact, both in this body of research, as well as consideration for future efforts.

4.4.1 Internal Validity

The results of this research have three main concerns with regards to their internal validity. These concerns are related to the potential for treatment diffusion, the possibility of cheating during the test, pre-test learning effect, and external influence upon the dependent variable.

During the administration of the experiment, it became apparent that efforts to create opaque walls between the treatment groups were not entirely effective. Within a few days of beginning the experiment, the authors received e-mails from concerned students asking why they didn't get to "play the game." Quick examination of the server database revealed that all of these students were in the control group. None of the participants in any other experimental groups inquired about the differences between the various game versions, but it would seem likely that the control group participants were not unique in being exposed to the interventions assigned to other treatment groups.

The underlying intent for obscuring the different treatment groups from the participants was to maintain the integrity of the treatment groups in order to reduce the potential for treatment diffusion and compensatory rivalry effects between the respective subjects. While the effects of compensatory rivalry may be harder to judge, the high investment requirement in participating in the experiment, or even playing just one game, makes the likelihood of treatment diffusion effects very low. Even if a participant were to find out about the other treatments, actually using these other treatments, due to the setup of the TEP program, would involve a significant amount of effort. While it feasibly could have happened, it does not seem likely to have happened, at least not with sufficient frequency to have affected the outcomes.

There also exists the specter that the conveniences of the experiment design also created the potential for participants to cheat while using the program by referencing some external aid. Looking at the pre-test data, there are some anomalous results at the upper end of the spectrum, as shown in Fig. 18. There is no evidence that these scores are the result of cheating, but regardless, they represent likely outliers in the distribution. It is presumable that someone who scores that highly on the pre-test may not fit the desired participant target demographic descriptor of a “novice” in the target learning content

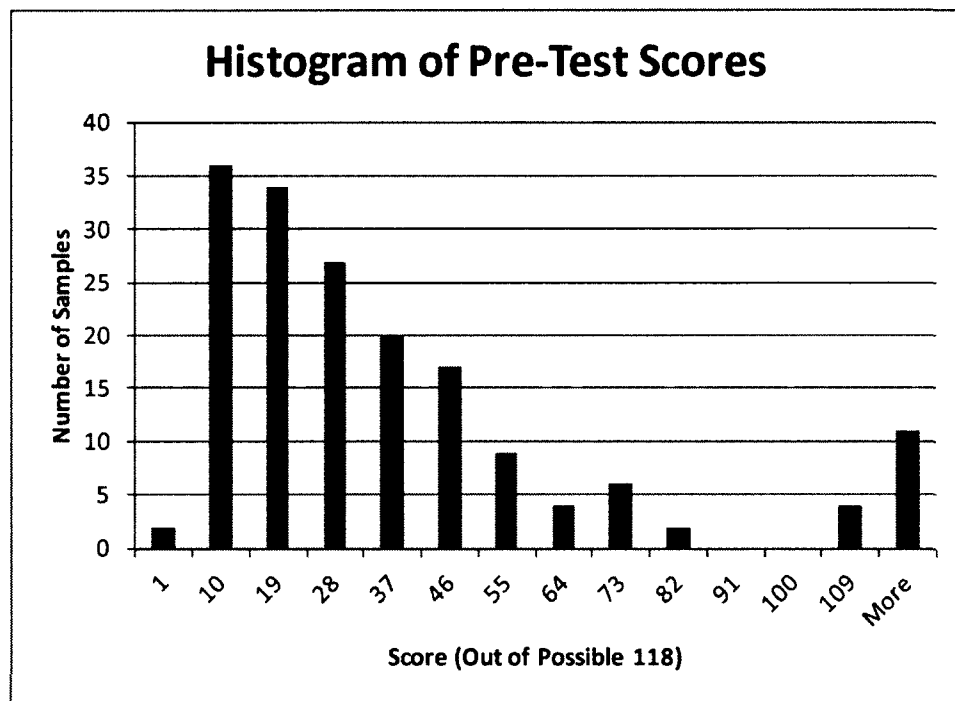


Fig. 18. Histogram of Pre-Test Scores

In spite of these potentially outlier values, t-tests on the experimental data with those participants culled out do not produce dramatically different results. The p-value

for the difference between the Baseline and the Degraded Aesthetics group drops slightly to 0.016. The difference between the Baseline and No Choice groups does drop to 0.11, but it is still not below the critical value of 0.05. And lastly, the p-value for the difference between the Baseline and No Competition group increases slightly to 0.35.

With regards to the pre- and post-test design, it is presumable that the rep-test cued the study participants to the learning content, and created an independent learning effect, outside of the experimental treatments. The control group served as the experimental mechanism to nullify any learning effect resulting from the pre-test. The effect could have been addressed via a Solomon 4-group design, but that would have required a significantly higher number of participants. There was an expectation that the pre-test would create some sort of content sensitization, and the data suggests that the control group improved their performance, on average, by 7.92 elements. The data allowed us to compare the Baseline performance against the Control group performance and see that there was a statistically significant difference. Additionally, all remaining comparisons were made from the Baseline, rather than the Control group.

Another threat to internal validity was the potential that the participants studied the learning content material outside of the context of the research. As described earlier, the learning content selection for these games makes diminishes the probability of this threat having an impact on the study. The pilot study conducted with students from the local chapter of the American Chemical Society revealed that memorization of the periodic table is not something that emphasized even in Chemistry oriented curricula. To account for this potential factor, however, the participants was selected from a suitable

pool from which the learning content specific to Element Solitaire© was not likely to be emphasized.

4.4.2 External Validity

External validity threats for this research are mainly in the form of concerns over generalizability. Specifically, three concerns are the generalizability of this research: the population, the content matter, and the games themselves.

With regard to the participant population, almost all participants were in the same undergraduate age group from the same body of students within the same college at Old Dominion University. There is a potential that there is a demographic effect that has biases this group towards the use of the serious games. There may be a demographic or generational predisposition towards games within some groups, however, it is worth noting that reports from the Entertainment Software Association indicate that the average age for people who use games is increasing, and that it is become more popular across demographic groups [64].

Generalizability concerns with the subject matter leave open the possibility that the learning content focused on in this research intrinsically influences the measured learning outcomes. The concern might be that different types of learning content may produce different learning outcomes, even if they were to be presented under the same conditions. The qualification that the learning content be categorized as declarative knowledge alleviates this concern to a small degree. This concept will be explored more in the coming chapters, as the examination of the interaction between games, learning

content classifications, education subject matter, and game genres are examined more in depth.

Lastly, the subjective nature of game design and program implementation creates noteworthy challenges to the board application of the principles set forth herein. Even if a game were to fulfill all the analytic and synthetic propositions of a serious game, there is no guarantee that the game would be a good game. Commercial game designers tend to refer to the process as an art, rather than a science [19, 65]. Games are intrinsically imbued with a highly subjective degree of quality, and even highly successful game designers cannot guarantee that the products they design will have the desired impact upon the player. The best way to mitigate this threat would be to test a variety of serious games and to create a process for assessing the quality of the game. The following chapters will begin to explore the potential of those different game design implementations, but a full empirical exploration of those questions will, in large part, remain beyond the scope of this current research effort.

CHAPTER 5

THEORETICAL BASIS FOR SERIOUS GAME DEVELOPMENT

Chapter 5 lays the ground work for further theoretical investigation of the principles which affect serious game development. It examines additional literature and research in both the entertainment software development and the instructional design fields and synthesizes a set of principles to guide serious game development. The intent for these principles is to provide practical guides which help developers create effective serious games.

5.1 The Relationship between Games and Learning Content

The examination of the propositions described in Chapter 2 is intended to aid in the development of quantitative data which provides insight into how serious games should be implemented, and how to make them more effective. The empirical results of this work help to solidify the theoretical foundations explored previously. The next two chapters of this dissertation will look at the process of building further upon that foundation. Using the combination of theory and evidence, the intent here is to use the results to create a practical serious game design process and principles which can aid serious game developers and users.

This combination of analytic and synthetic propositions and experimental results serve as conceptual guides from which to begin explore the relationships between games and learning more closely. Serious games, as described above, should result in learning or training transfer. In order to do so, the serious game designer or creator, has to

interweave the serious half and the game half into a cohesive whole. Attempting to do so raises interesting questions, such as:

- Where and how game and learning content mix?
- How do the learners benefit from this mix?

Answering these questions may begin by exploring Gee's concept of a learning space in a little more depth [4]. Gee's statement on learning space was first discussed in section 2.3.1, and concerns the notion that games provide a learning space that the player can explore. Gee does not explicitly define the concept of the learning space, but from his description, it might be inferred to be a part of the diegetic world created by the video game. When a learner engages with the game world, they do so with few of the risks that might be inherent in performing similar activities in the real world. They are free to explore the learning content.

For the purposes of closely examining or even trying to create a learning space, it can be helpful to draw further distinctions between the game environment and the learning space. A learning space might not include everything that is included within a game. The learning content may be restricted to only certain subset of the diegetic space defined by the game, with other portions of the game having little or no bearing on the intended instruction. Based on this paradigm, a serious game designer should consider where the learning content belongs in the game. More fundamentally, we should consider whether this distinction between learning and non-learning "space" of the game does, indeed, matter.

Anecdotal observation seems to support this notion that in most cases, the learning content in serious games does not make up the entirety of the experience.

Games are likely to include aspects which are not related to the instructional material. This can be seen most readily when the motif of a game, as defined by Christopher Totten [66], is not specifically dictated by or dependent upon the learning content. Totten distinguishes between the mechanics and the motif of a game, with motif comprising aspects of the game like narrative and themes. Motif is the aesthetic or thematic presentation of the game beyond the mechanics which embed the rules. Hunicke, et al. similarly associate game aesthetics with the emotional “fun” response evoked by the player interacting with the game [67]. In the business model simulation game *Lemonade Stand*, shown in Fig. 19, the distinction between aspects of the motif and the learning content are clearly visible [68]. The game is intended to teach about the challenges of running a business, but the aesthetics of dogs, cats, and strange creatures have no bearing upon that content.

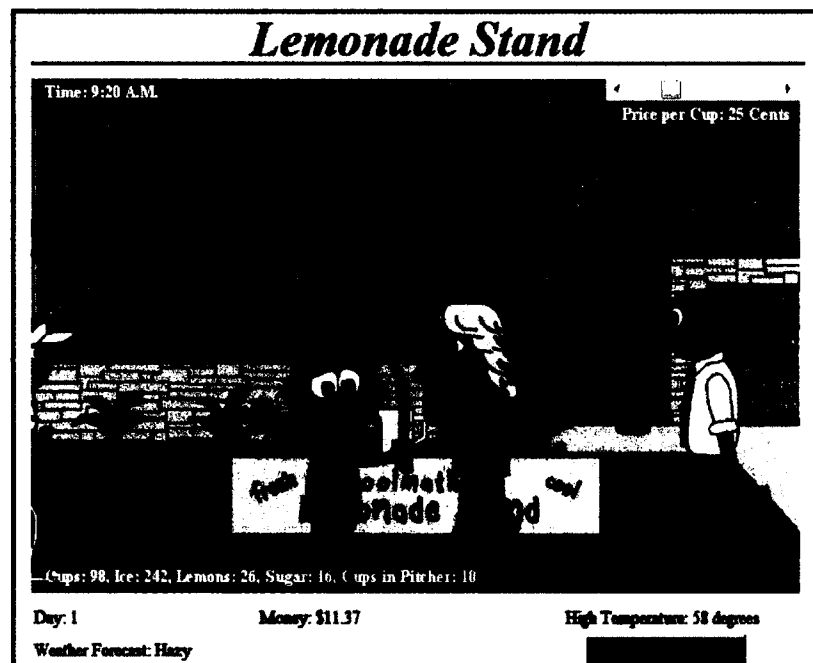


Fig. 19. Lemonade Stand, by Coolmath.com, Inc. [68]

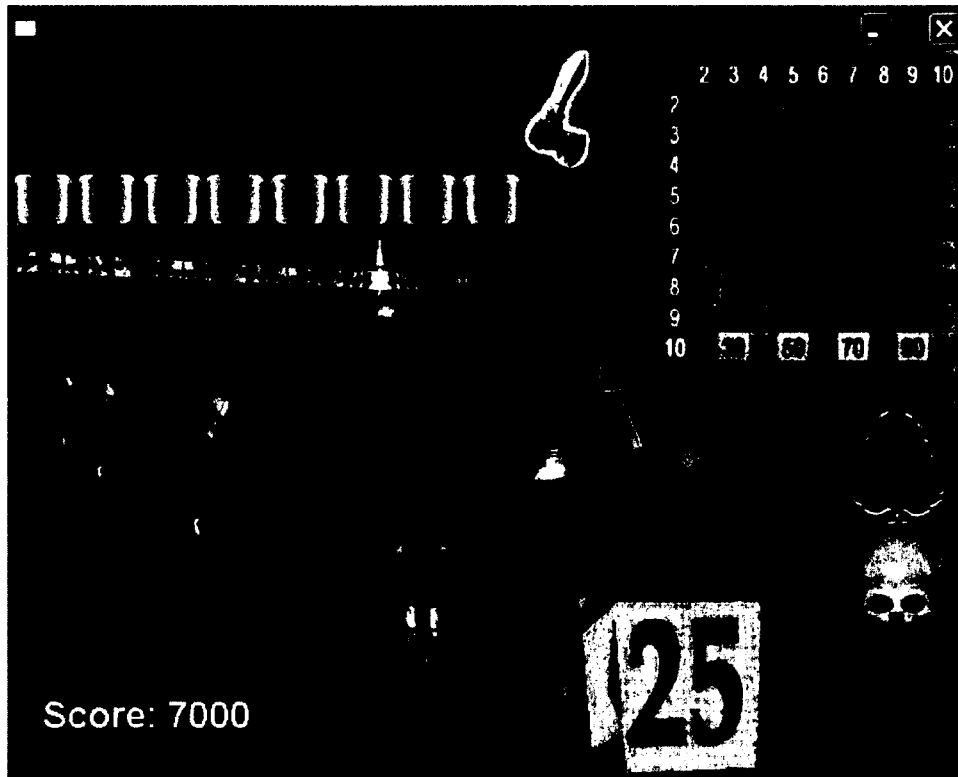


Fig. 20. Zombie Division, by Matthew Habgood [69]

Even while serious game developers and researchers stress the importance of integration of game fantasy and learning content, there is still evidence that the motif and mechanics do not entirely overlap with the learning content. M. Habgood, et al. created a game to teach division skills and demonstrated the importance of endogenous fantasy in which the fantasy of the game is intrinsic to the learning content and vice versa. Yet a screen shot of the game still shows that it is challenging to not include aesthetic content in a game that is not necessarily related to the learning content [70]. Fig. 20 shows Habgood's *Zombie Division* game, in which the learner must use numerically oriented weapons to "divide" the enemy skeletons. Even though the game is cited as an example of intrinsic fantasy, it is clear to see that the motif is not directly relevant to mathematical division. The aesthetics of the game depict a small Greek warrior attacking skeletons,

and the linkage between these fantasy characters and division is created through the mechanics of the game, not the motif.

Based on these examples, it may be concluded that the learning space is a subset of the larger game environment, and that further, the learning space is a result of the interaction of learning content with the game elements (mechanics and motif). In part, the learning content may be presented in the game or simulation through expository methods, such as narratives, cut scenes, or non-interactive demonstrations. But the learning space which the game users actively explore is created when the learning content is made available to the user through game-play. It is through these mechanics that the user has a chance to meaningfully interact with the content. Fig. 21 depicts the relationship between Game, Learning Content, and Learning Space. The next challenge is to understand how designers create game-play for the users.

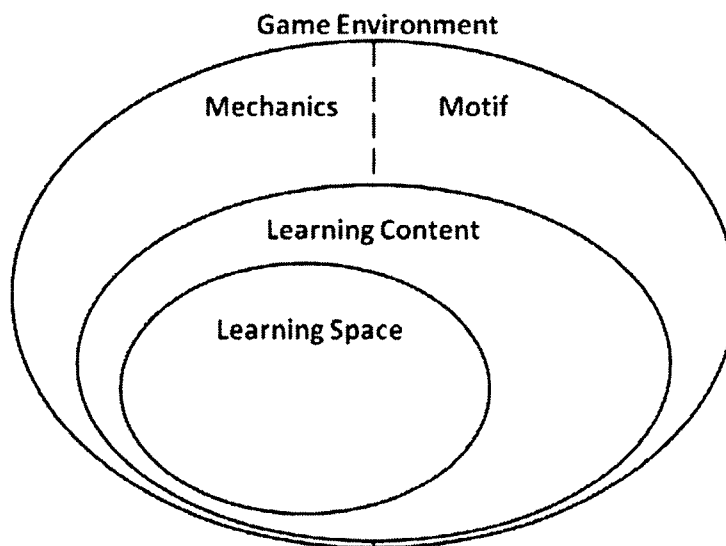


Fig. 21. The Relationship between Game Environment, Learning Content, and Learning Space

5.2 Operative and Resultant Actions

In *The Art of Game Design*, Schell discusses two important concepts which play a significant role in shaping game mechanics. These concepts are the users operative and resultant actions [19].

Operative actions are the basic actions which a player might engage in. In a game of checkers, these operative actions might include moving a checker forward, jumping an opponent, or moving a king backwards. Due to the nature of computers, video games must explicitly delineate these actions and their effects. As a result, in computer games, these actions tend to be very discrete and well defined.

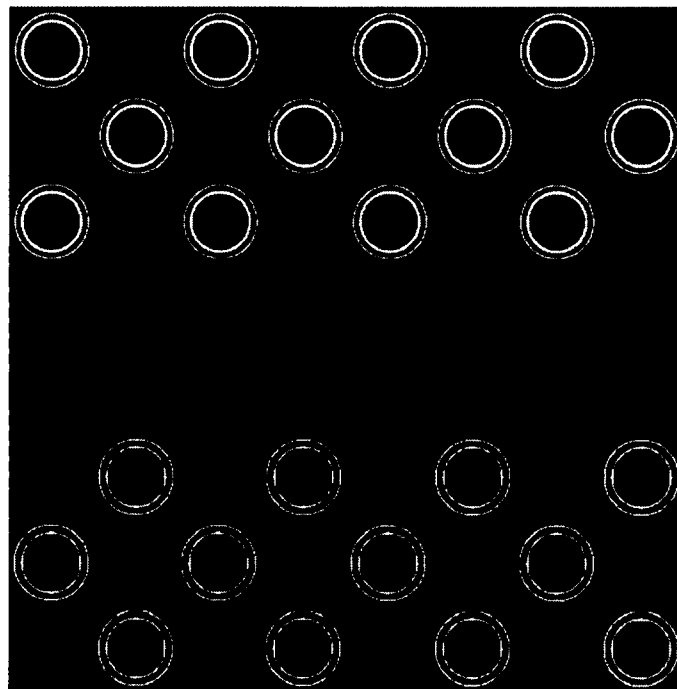


Fig. 22. Checkers Board

Resultant actions, on the other hand, are the “meta” actions which the player can take, in order to achieve a goal. In the example of checkers, the player might force an

opponent to make an unwanted jump, or protect a piece from being taken. Both of these resultant actions might take the form of the same operative action (moving a checker forward), but they serve different purposes, and are enacted for different reasons. Schell describes how these actions are often not a defined part of the game, but rather are emergent aspects which develop through game play. As such, they are ill-defined, and more subjective than operative actions. To an extent, these resultant actions are analogous to strategies developed to achieve goals within the game. Even in video games, these actions have a larger degree of latitude than their operative counterparts.

Schell also discusses the interaction of operative and resultant actions, and their effect upon the complexity and the potential for emergence in a game. From this discussion, it is possible to discern some basic formulae with which to characterize the games in terms of complexity, elegance and depth. The following are proposed definitions of these terms, in the context of Schell's actions.

Complexity may be thought of as a reflection of the operative actions. Games are complex when the user has many specified actions they can take. A game of chess, for example, is a relatively more complex game than checkers. The chess player has many operative actions; each side consists of sixteen pieces, made up of six unique types. These unique types each behave differently, providing the player with distinct operative actions for each piece on the chess board. In contrast, as mentioned above, checkers has fewer operative actions for the player to consider.

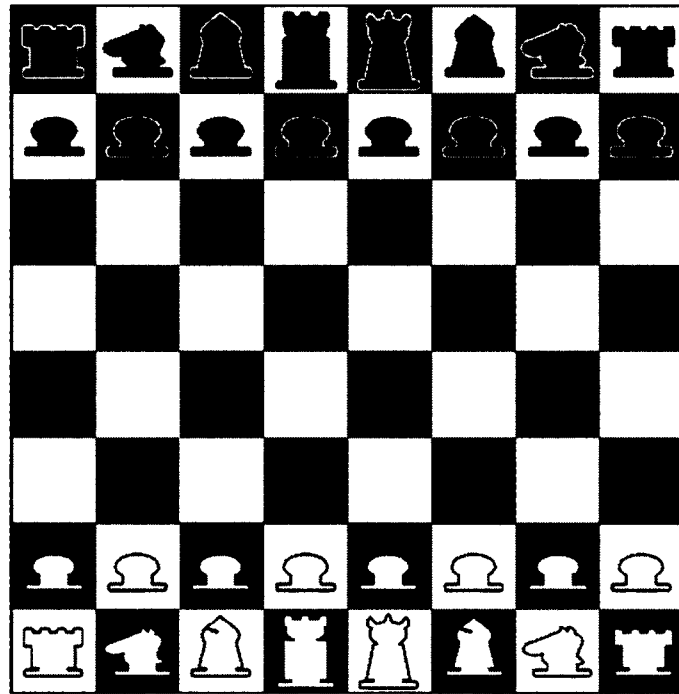


Fig. 23. Chess Board

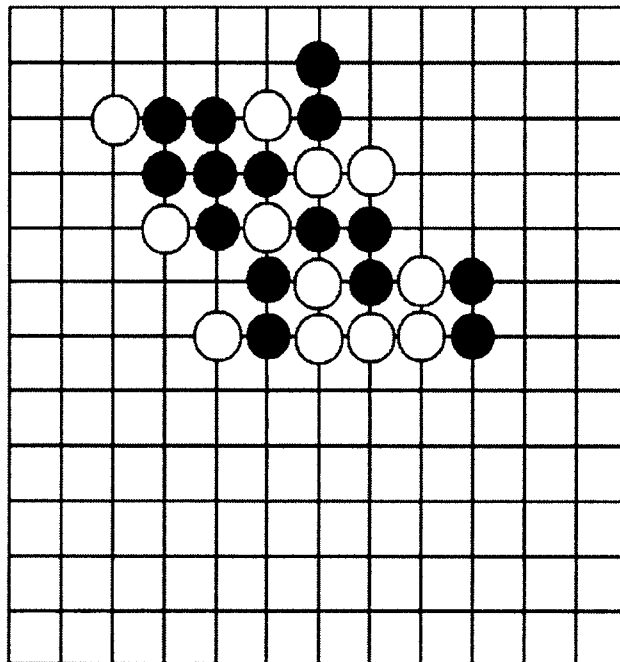


Fig. 24. Go Board

Elegance, on the other hand, can be considered the ratio of resultant actions to operative actions. Games that are elegant have more resultant actions in comparison to the number of operative actions. The game of Go is a good illustration of elegance. Go only has two operative actions – to place a stone on the board, or to pass. All stones are identical, and behave the same, and the action of placing the stones is the same every time. However, Go, like Chess, still has an abundance of resultant actions.

That abundance of resultant actions sums up the last characterization: depth. Schell suggests that one way to create the potential for resultant actions through the addition of clever and interactive operative actions. However, he simultaneously cautions that too many poorly considered operative actions can result in a game that is “bloated, confusing, and inelegant” [19]. Games which are elegant achieve depth while keeping complexity to a minimum.

From the Instructional Design perspective, Morrison, et al. provide specific prescriptions for designing instruction based on the type of learning content [71]. In examining these prescriptions, it seems likely that it is in the depth of the game, rather than the complexity of the game, that the user might engage in activities that would support teaching principles, rules, and procedures. In contrast, if the learning content is limited to facts and concepts, requiring lower levels of Bloom’s Taxonomy [72, 73], then it may be sufficient to embed the learning content into the operative actions, or even in the game motif.

Schell’s operative and resultant actions provide the serious game designer with a means by which to instill desired levels of complexity and depth into a game. By manipulating these elements of the game design, game developers can attune their game

design to support instructional needs. But the potential pedagogical implications for operative and resultant actions are even farther reaching.

5.3 Learner Expertise and Learning Curves

The balance between operative and resultant actions may have bearing not only on the learning space created and the elegance of the game, but may also on the type of learner for which the game is designed.

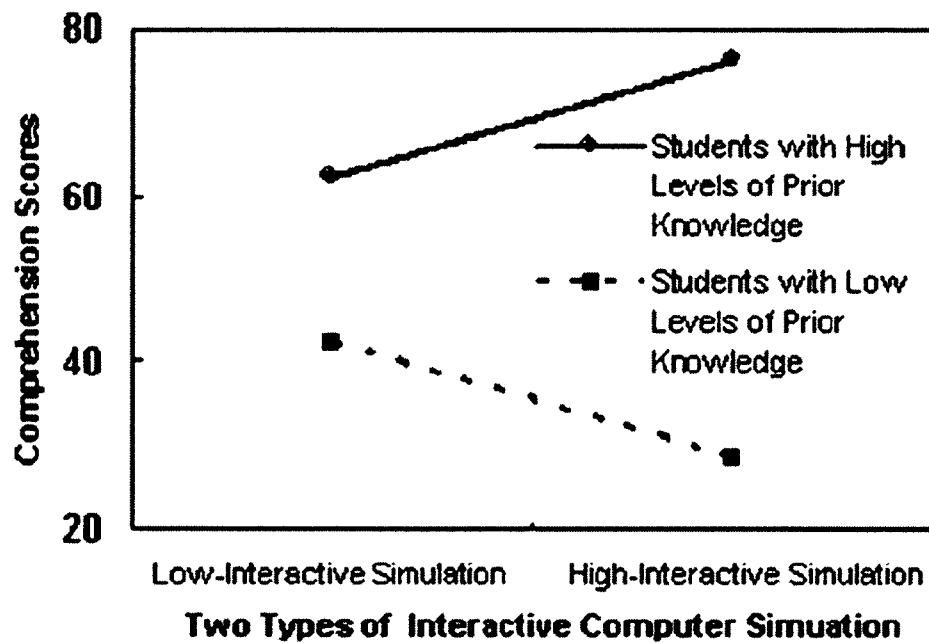


Fig. 25. Results of Experiments Conducted by Park, et al. [74]

S. Park, et al. studied the use of simulations with high and low levels of interactivity by experienced and novice learners [74]. One conclusion drawn was that experienced learners did better with more complex simulations, while inexperienced learners performed relatively worse. Within the Park's research, the difference in the

complexity of the simulations can be largely described as a difference in the amount of operative actions given to the users. The results of their research also indicate that the mean cognitive load score (the mental effort required to learn the content) for inexperienced students increased along with the increase in complexity, while the mean cognitive load score for experienced students decreased. Fig. 25 shows the results from Park, et al.'s research.

Based on this research, it would follow that advanced learners would benefit more for having many operative actions through which to interact with their serious games. Designers targeting such learners would be free to include many operative actions, presumably creating both complexity and depth. In contrast, serious games designed for novice learners should focus on elegance, reducing the number of operative actions in order to reduce the complexity of the game interactions.

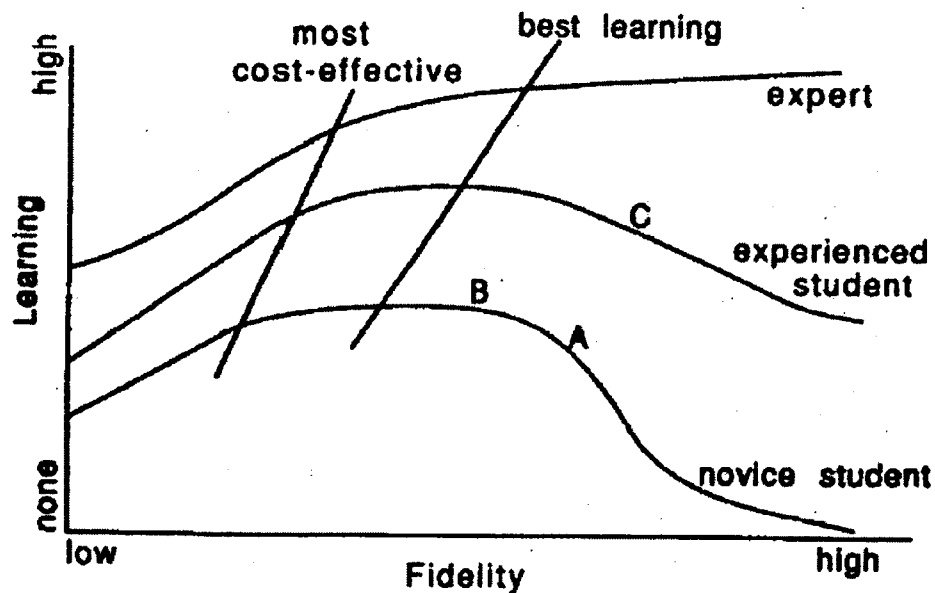


Fig. 26. Alessi's Hypothesized Learning Curve [75]

The results of Park, et al.'s research bear a remarkable resemblance to the hypothetical learning curve suggested by S. Alessi [75]. Fig. 26 depicts Alessi's curve. Park's graph only presents 4 data points, making it difficult to ascertain whether the data fully describes the curve, but experimental results seem to support the hypothetical curve.

Alessi's curve is hypothetical, and his article concludes by stating that future research should assess what aspects of a simulation should be varied and under what conditions this variation should occur. Park's data suggests that interactivity is one place in which variation should occur, and Schell's actions further suggest that manipulating the operative actions made available to a learner may be a good prescription for calibrating a game to the needs of the learner.

It should be noted that Alessi is comparing learning to simulation fidelity, while Park, et al. are describing learning (as reflected by comprehension scores) against the levels of interactivity in the simulation. In order to make the leap between the two graphs, it must be presumed that interactivity is correlated with simulation fidelity.

The justification for making this leap between interactivity and simulation fidelity may be found in J. Sweller's definition of cognitive load, and its three components: intrinsic, extraneous, and germane load [76].

Intrinsic cognitive load results from the difficulty of the material being dealt with. Extrinsic cognitive load is created by the manner in which the material is presented, and lastly, germane cognitive load is the load associated with processing and encoding schemas. Alessi defined fidelity as the degree to which a simulation reflects reality, or the phenomena being presented in the instructional content [75]. Park's presentation of simulation complexity via interactivity is a clear reflection of the intrinsic load being

imposed on the learner [74]. Based on these definitions, simulation fidelity correlates mostly to the intrinsic cognitive load, while simulation or game interactivity correlates to extrinsic cognitive load.

Complexity and fidelity form two sides of the cognitive load triumvirate, and experimentation by Lee, et al. concludes that adjustments of presentation (and corresponding intrinsic load) can be used to calibrate the overall cognitive load [77]. Additionally, their experimental results are similar to those of Park, et al., though their experimental design included an additional factor comparing iconic versus symbolic representation. Increasing or decreasing the extraneous cognitive load presented to the learner can compensate for their experience level with the learning content. If the learner is experienced, then they can be effective with complex presentations, whereas novice learners should be given more simple interfaces in order to account for their position on the learning curve with respect to the intrinsic difficulty of the subject matter. As before, the moderation of the extraneous cognitive load can be performed by adding or removing operative actions.

5.4 Summary

Serious games embed their learning content in manner in which the learner can interact with the learning content within the learning space, inside the game environment. The type of learning content makes difference in the way in which the learning content should be presented. Learning content on the lower spectrum of Bloom's Taxonomy can be predominantly embedded within game aesthetics, while learning content at the upper end of the spectrum need to be embedded more in the actual game mechanics. Lastly,

serious games for novice learners should restrict the number of operative actions presented to the player, which expert learners benefit more from have many operative actions to choose from.

CHAPTER 6

SERIOUS GAME DESIGN PRINCIPLES AND PROCESS

This chapter presents a serious game design process, based on the theoretical principles described in Chapters 2 and 5, as well as the experimental results described in Chapter 4. This process is then examined through a variety of lenses. It is used in the development of two serious game prototypes, and as a means of developing several additional serious game concepts. It is also used to examine a selection of existing serious game designs. These development and examination efforts demonstrate the potential of the serious game design process in a variety of roles.

6.1 Serious Game Design Process

The ultimate goal for this research is to create a practical serious game design process and a set of principles based on the theoretical foundations and the results of the empirical research. The theoretical basis discussed in Chapter 5 suggests several serious game development heuristics. When used in concert, these heuristics form a serious game design methodology. As presented, this is not intended as a strict step-by-step procedure, but rather as a means of pulling together the highlighted theories in a coherent manner. While the steps flow in a logical order, it is likely that a serious game designer might visit them out of sequence during the development process, in organic response to each game's unique growth. It is also likely that steps would be revisited multiple times, as the game is iterated upon and evolved. The outline for the process is shown in Fig. 27.

Proposed Serious Game Design Process

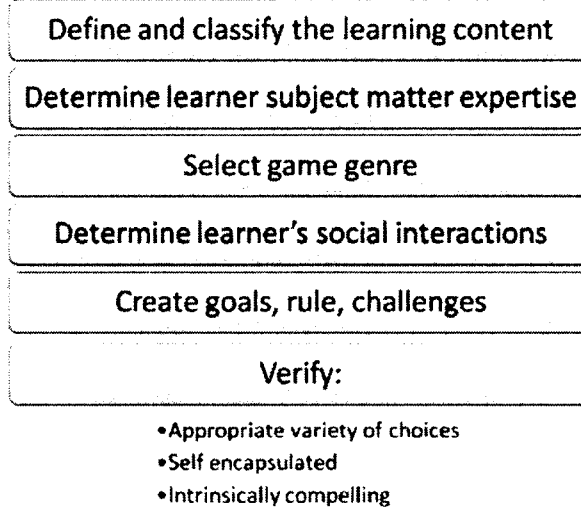


Fig. 27. Serious Game Design Process

6.2 Exploration of Process Steps

The following sections will detail each step of the Serious Game Design Process. They will explore and detail relevant research and background material supporting each process step.

6.2.1 Define and Classify the Learning Content

The first step in this methodology is to define the learning content and classify it. Unless the developer has the unlikely luxury of creating a curriculum in a vacuum, the learning content will likely be externally determined. The classification process is a simplification of assessing the content along in terms of Bloom's Revised Taxonomy [72, 73]. The exact nuances of which level the content lies in are not strictly important. Rather it may be sufficient to assess where the content lies between the spectrum of declarative and procedural knowledge, as shown in Fig. 28.

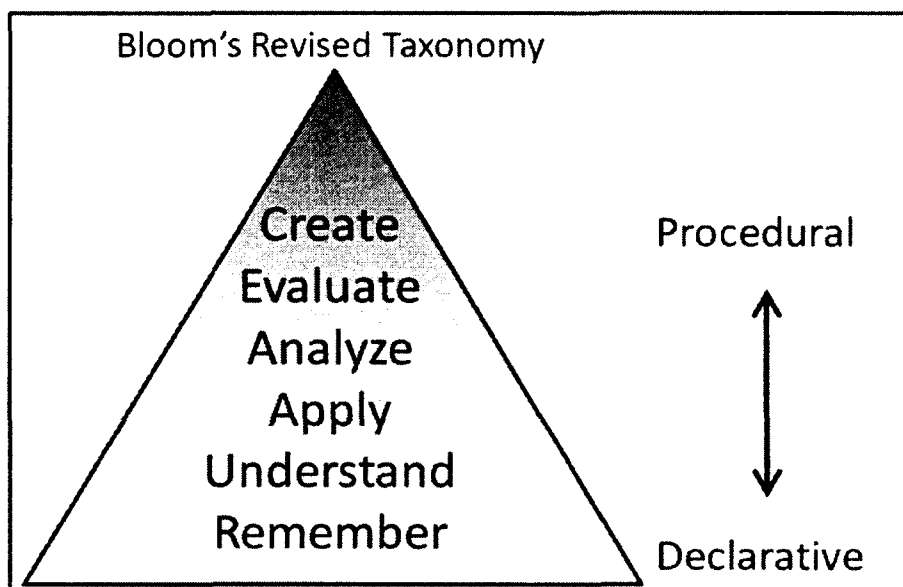


Fig. 28. Relationship between Bloom's Revised Taxonomy and Content Classification

In turn, the categorization will inform the manner in which the learning content is embedded into the game. Declarative knowledge may be simply conveyed via the game aesthetics. The simple presence of the content within the game can provide the learner with repeated presentation of the content, which is a common strategy used in instructional design [78]. Aesthetic embedding opens a breadth of game development choices, as the “theme” of the game may simply be adjusted (within reason) to accommodate the learning content. On the other hand, procedural knowledge requires a more sophisticated integration of the learning content into the game. The rules and procedures fundamental to the learning content will likely play a large role in governing how the game mechanics function. This is an important consideration to bear in mind when selecting (or creating) a game genre upon which to build the serious game.

6.2.2 Identify the Learner

Step two is to identify the target learner. For this purpose, the learner description is primarily concerned with the learner's expertise level with regards to the content. This descriptor will range from novice to expert. In accordance with the theoretical basis, the learner's level of expertise will determine the target level of complexity for the serious game. The learner's expertise determines how intricate the game will be; how many options will be available to the learner. This determination frames the further development of the serious game, and shapes many considerations for the game's implementation.

There are other considerations for the target audience as well, including many of the standard demographic descriptors. Most of these are consistent with the learner or player survey which would take place in most educational or software development efforts, and will not be addressed in detail here. The only exceptional consideration to highlight is the learner's access to videogame platforms, as that will obviously impact how much interaction the learner has with the game. The serious game developer should consider how the game will be distributed, whether through the internet as a download, in a web browser format such as Above Flash© or Microsoft Silverlight©, or as a distributable disc. Additionally, the developer should consider how much access the learner will have to the game. Will it be something they can access any time they like (from a home computer, or even on their phone), or will be something which they engage with only under directed circumstance, such as in a classroom or training site.

Unfortunately, there arise times in which the serious game designer may be uncertain as to the exact nature of the learner, or the learner base may be so wide as to

defy neat categorization. In these circumstances, it is still desirable to define a nominal learner as the primary target of the serious game. If there is a requirement for the game to serve a wide variety of learners, the game developer might have to spend additional time making the game adaptable to meet the needs of these different learners. For example, the game may include dynamic scaffolding, which supports novice learners, and then drops away as they demonstrate their expertise in the subject matter. The game can also create a dynamic adaptive learning environment in which the challenge is raised in accordance with the learners selected or demonstrated capabilities.

As an example of this adaptation, Element Solitaire© offers multiple levels of difficulty that allow the learner to play with 36, 54, and 84, or 118 elements. Additionally, the game can be played in Escalation mode, which presents the elements one row at a time, or in Challenge mode, which randomly draws elements from all of the rows. Though these options do not automatically adapt to the learner's expertise, they do permit some degree of flexibility that allows the game better provide for the player's instructional needs.

6.2.3 Select Game Genre

Once the learning content and learners have been identified and classified, the next step is to consider the game genre. Looking at existing game genres is helpful, especially to a new game developer, as genres can be thought of as a template for game design. Genres provide insight into the natural evolution of effective game types, honed over more than three decades of collective game development experiences. Understanding these templates aids designers in understanding design choices as well as

player expectations. Additionally, looking at genre exemplars can provide inspiration for the development of the game.

Some game designers may consider choosing a genre this early in the design process anathema. Chris Crawford describes a purer game development process whereby the designer first fixes a goal in terms of player experiences, and then methodically develops a theme (or topic as he refers to it), and then organically grows the game structure to support that goal [17]. While this may be a purer and more artistic way of creating a game, it is worth considering that Crawford's seminal work was written very early in the history of commercial video games, and many genres have firmly established themselves over the intervening decades.

In considering the genres, a designer walks a fine line. Genres can serve as useful guides, though designers should avoid feeling constrained by them. It is well worth taking the time to consider the development process with a "genre blind" perspective. However it is also unnecessary to reinvent the wheel, oblivious of the history of video game successes and failures. As with design patterns in computer programming, or even generic classes in object oriented coding, genres serve as suggestions that should be used, modified, or discarded as needed.

It would also be a mistake to construe the examination of genres for an inspiration or a guide as synonymous with wedging learning content into existing games. As Habgood's research illustrates, there is genuine value in crafting a game to support the learning content [69]. Shoe-horning learning into a non learning game will not encourage the player to engage with the learning content. Most likely, it will do the opposite, or encourage the player not to play the game at all. Rather, genres should be considered

carefully and only used when the genre and learning content seem well suited to each other, or the designer develops an exciting way to blend the two together.

Some of the widely recognized game genres, as identified by the Entertainment Software Association, include Sports, Action, Sports, Family Entertainment, Shooter, Racing, Adventure, Strategy, Role-playing, and Fighting Games [64]. The following are brief descriptions of each genre, as well as the percentage of console video games of that game genre in terms of units sold in 2009.

- **Sport Games (19.6%):** feature realistic simulations of traditional sports based on real-world rules and physics, such as soccer in FIFA Soccer 12 by Electronic Arts[79], basketball in NBA 2K12 by 2K Sports[80], and football in Madden NFL 12 by Electronic Arts[81].
- **Action Games (19.5%):** require quick player actions and accurate eye hand coordination to overcome obstacles. Several other game genres can be considered as subcategories of action games. Examples of this genre include Super Mario Bros, by Nintendo [26], Bayonetta by Sega Corporation [82], and Ninja Gaiden by Tecmo [83].
- **Family Entertainment Games (15.3%):** are games that are suitable and fun for the entire family, such as music simulation like Guitar Hero by RedOctane [84], dancing games like Dance Central by MTV Games [85], and fitness games like Wii Fit by Nintendo[86].
- **Shooter Games (12.2%):** are mainly combat actions using various weapons, such as guns and missiles. Based on the camera views, shooter games can be classified

in to first-person shooters and third person shooters. Examples include Halo: Reach by Microsoft [87], Call of Duty 4: Modern Warfare by Activision [88] and Medal of Honor by Electronic Arts [89].

- **Racing Games (6.7%):** provide realistic simulations of high-performance vehicles in various environments such as city streets, rural roads, and racing tracks. Examples include Need for Speed: World by Electronic Arts [90], and Forza Motorsport by Microsoft [91].
- **Adventure Games (6.6%):** feature complex and intriguing environments for the players to explore for the purpose of collecting treasures, solving puzzles, finding secrets, etc. Examples include Grand Theft Auto IV by Rockstar Games [92] and Uncharted by Sony Computer Entertainment [93].
- **Strategy Games (6.4%):** require careful thinking and planning to achieve the goal. Based on the time restrictions, strategy games can be classified into turn-based strategy (TBS) and real-time strategy (RTS) games. Examples include Starcraft by Blizzard [94] and Civilization V by 2K Games [95].
- **Role-Playing Game (5.8%):** allow players to take on different roles in fictional settings or simulated world. Examples include Final Fantasy by Square Enix [96] and Mass Effect 2 by Electronic Arts [97].
- **Fighting Games (4.1%):** emphasize two-person combat using various weapons such as swords. Examples include WWE Smackdown vs Raw 2011 by THQ[98], and Street Fighter by Capcom [99].

In conjunction with these “typical” genre classifications, however, there exists a broader game classification which should be considered. This distinction is whether the game will be a “traditional” style game, or a “casual” game. Jesper Juul differentiates traditional and casual games with five criteria: fiction or emotional valence, usability, interruptability, difficulty and punishment, and “juiciness” [46]. Casual games tend to have a positive fiction or emotional valence, depicting pleasant or light themes, while traditional games tend to focus on negative or dark fiction, such as war or other traumatic experiences. Casual games also undertake a concerted effort to make their games highly accessible and easy to use. In contrast, traditional games tend to build upon collective gamer knowledge to create highly sophisticated, yet potentially less accessible experiences. Similarly, casual games are designed to accommodate sporadic attention to the game play, while traditional games tend to demand player’s attention over longer periods of time. Casual games also are normally more forgiving, and even when they present a high level of challenge, casual games do not punish players for their failures as much as a traditional game might. Lastly, though very closely associated with emotional valence, Juul describes how casual games tend to be almost excessively affirmative and offer the player highly positive feedback for their actions.

Juul highlights how traditional games tend to focus predominantly on male video game consumers between the ages of 18 to 34. The advent of casual games has expanded the video game consumer base to encompass a much wider demographic range, both in terms of gender and age. In this regard alone, serious games may well be better served by adhering to the casual game model. In general, this wider appeal and lower barrier to entry will serve the educational needs of a serious game better than a traditional game.

However, the desired complexity of a game or its content may very well lead a developer towards a more traditional style of game. America's Army is an example of a serious game which eschews the casual game model, and seeks to create a more traditional first person shooting game [100].

The decision to create a casual or traditional type of game is also related to identification of the learner's expertise level. Novice learners are likely to be better served by a casual style game. The complexity tends to be diminished, and the overall experience tends to be more approachable and suitable to the uninitiated. On the contrary, an expert learner might be turned off by a serious game that does not treat the subject matter with a sufficient degree of depth. A complex serious game, like a traditional game, could be more focused on creating a highly sophisticated game in order to convey the more nuanced content, and less constrained by the need to cater to the intellectual and attitudinal needs of an uninitiated player.

Another consideration to be taken when selecting a genre for the game is the specific interaction that might take place between the game genres and desired learning content. To facilitate this consideration, the chart shown in Table 8 has been created, which lists public school subjects, as defined by the Virginia Department of Education (DOE) [101] against the ESA listing of game genres. The Virginia DOE was selected as a convenient and accessible exemplar of K-12 curricula. This "Subject Genre" Table has been populated by examining an available online database entitled Serious Games Classification [102]. This database is an open, crowd-sourced database maintained by a research and development initiative called Ludoscience. By populating this chart with the number of observed occurrences of each intersection of game and genre, it is possible

to begin assessing trends which seems indicative of the ways in which game genres have been selected for serious games.

Table 8. Subject Genre Table

	Sports Games	Action Games	Shooter Games	Racing Games	Adventure Games	Strategy Games	Role-Playing Games	Fighting Games	Family / Casual / Puzzle Games	Total
Total	9	53	10	7		82	9	5		
English	0	0	0	0	0	0	0	0	2	2
Mathematics	4	28	3	4		29	0	1		
Science	1	7	3	1	44	21	0	0		
History & Soc Sci	3	7	3	0		30	5	3	37	
Family Life	0	1	0	0	0	0	0	0	0	1
Econ. & Personal	0	0	0	0	0	1	2	0	0	3
Fine Arts	0	1	0	0	3	1	1	0	5	11
Foreign Lang	1	1	0	1	9	0	0	0	19	31
Computer Tech	0	0	0	0	0	0	0	0	1	1
Health	0	8	1	1	5	0	1	1	34	71
Physical Ed	0	0	0	0	0	0	0	0	0	0
Driver Education	0	0	0	0	0	0	0	0	0	0

The cataloguing of the games was a simple process of identifying a game, and crediting it to the appropriate location on the chart. For example, Habgood's Zombie Division would be a credited to the intersection of Math and Action Game [69]. Oregon

Trail would be credited to the intersection of History and Adventure Game [103]. Many games in the database were tagged with multiple genres, such as action and racing combined. The database provided a rudimentary query feature that helped roughly identify relevant games, but additional inspection was often needed to verify the query results. For example, the query of “English Puzzle” games returned some relevant results, like “Ziggi’s First ABCs”, and some erroneous results, like “Donkey Kong Jr. Math”.

When looking at the ESA, it is worth keeping in mind that the ESA has an industry role in promoting and lobbying for video games. The Family Games genre is more a function of the Entertainment Software Ratings Board (ESRB) rating of a game than the style of mechanics of the game itself. Games that fit into The Family Entertainment genre category tend to be family safe games that can be enjoyed with younger children. However, this categorization is orthogonal to the other genres. Technically, provided that many of the games found in the database are “family friendly”, they could be reasonably attributed towards the Family Entertainment genre. For the same reason, it is also arguable to that the Family Entertainment definition is consistent with Juul’s definition of a casual game. For this reason, the two categories have been combined.

From the chart, however, we can see that Math is by far the dominant serious game genre, with 253 total game entries. This is possibly a function of the math friendly nature of computers in general. It is much easier, from a technical perspective, to create a program that assesses a user’s performance in a mathematical problem than one which parses the English language.

The subjects of Science as well as History and Social Science follow next, with 153 and 161 games respectively. Health and Foreign Languages are next with 71 and 31 games apiece, while the remaining subjects have 11 or fewer games each. Physical Education and Driver Education have no games in the database.

The lack of Physical Education games reflects a lack of entries in the database. Recent developments in motion sensing input for video game consoles have created a large and viable collection of physically oriented video games. Examination of the Virginia Department of Education SOLs seems to indicate that some of these games could be complimentary to a Physical Education curriculum, though for obvious reasons it would likely be preferable to simply have students participate in real life sports and exercise.

Similarly, the lack of Driver's Education games seems notable, if only because driving representation is so prevalent that Racing Games have their own ESA genre. However, most of the games encourage the type of driving that would not likely be complimentary to a Driver's Education curriculum. However, it would not be too challenging to imagine high quality driving simulations which could promote positive driving habits and help students learn necessary skills with significantly reduced risk and cost. A quick online check does reveal some available Driver's Education games.

From the genre perspective, we see that added category of Family/Casual/Puzzle genre has the most entries, with 321. This observation supports the supposition that this genre of games is highly adaptable to teaching a wide breadth of learning content types. When the serious game developer is trying to teach declarative knowledge, casual games and puzzle games provide a number of compelling game types that are thematically

reskin. Learning content can be easily overlaid via the aesthetic presentation of these games, and the core mechanics are often loosely associated with the learning content. Even if the learning content is procedural in nature, the puzzle or casual games can provide a convenient vehicle through which to present this procedural knowledge in an abstract manner. There is a low requirement in this genre for a consistent or believable endogenous fantasy. This might be contrasted with most of the other genres, where the fantasy and narrative of the game becomes highly important to the genre.

Indeed, it might be possible to create a three tiered hierarchy of how important the endogenous fantasy is to a specific genre. At the top of the hierarchy would be the role-playing game, where the fantasy is a highly integral part of the gaming experience. A role-playing serious game with procedural learning content would have to take great care to ensure that the desired content was consistent with the mechanics and fantasy of the game. Indeed, we see that among the role-playing games listed in Table 8, the majority of these games are in the History and Social Sciences subject, in which the narrative and fantasy could very well effectively be the learning content.

At the bottom of this hierarchy would be the Family / Casual / Puzzle games. These games are those for which the least amount of fantasy is required. Some of the most well known games in this genre, like Tetris, have arguably no fantasy in them at all. This makes them ripe candidates for accepting the desired learning content without fear of conflict or difficulty integrating the material. However, by their nature, these types of games may not create as deeply engaging a game experience as a genre with a richer fantasy component. For this reason, the Family / Casual / Puzzle genre may be more suited to declarative and simple procedural learning content.

Lastly, the remaining game genres would seem to occupy a middle tier of implicit endogenous fantasy. Within each of these remaining genres, there are examples of a wide range of game types, which span the breath from high to low degrees of fantasy. A prime example might be Racing genre. Some games within this genre, like the Forza Motorsport series or the Burnout series, create highly realistic and consistent worlds which the players engage in. Such games might have a higher barrier to accepting learning content outside of the narrow confines of the world which has already been created. On the other hand, the popular style of “kart” racing games, such as Mario Kart, tends to be much more whimsical and imaginative. Within these games, players expect to see things which are unrealistic or inconsistent, and so the opportunity to integrate the learning content within the game is greater.

With regards to serious games, the learning content may suggest certain genres over another. For example, historical content, might lend itself to the Adventure genre, as in the classic educational game, Oregon Trail [103], or the turn based Strategy genre, as in Sid Meier’s Civilization series [95]. Additionally, certain genres, such as the Family Entertainment, or tend to be very broad in nature, and include a variety of puzzle style games which are very light on theme. Because of the weak relationship between the theme and the game mechanics, these games lend themselves to easily being “reskinned”, allowing developers to easily add aesthetic based learning content, suitable for learning declarative knowledge.

When speaking about genres and game development, however, it is important to note that these genre definitions, to an extent, are constantly being pushed and tested by innovative game designers. Even with established, genres, the definitions tend to be

somewhat flexible. Game developers will frequently try to innovate by creating new genres or hybrid games which defy easy categorizations. Two prime examples are the games Portal, by Valve [104], and Minecraft, by Mojang Studios [105].



Fig. 29. Portal, by Valve [104]

Portal is innovative because it is a puzzle solving first person shooter game. The game puts players in the role of a test subject who must navigate certain challenges by using positioning portals within the terrain. The portals allow them to go into one portal and come out the other portal, regardless of where they are placed. The game is innovative because for a long time, the idea of jumping and puzzle solving was considered impossible to perform well within first person shooter games. The first person shooter perspective makes the sort of time and distance jumping needed for such a game notoriously difficult. However, Valve pushed the boundary of this assumption and

has developed two award winning games in the Portal series by successfully challenging the genre norms.

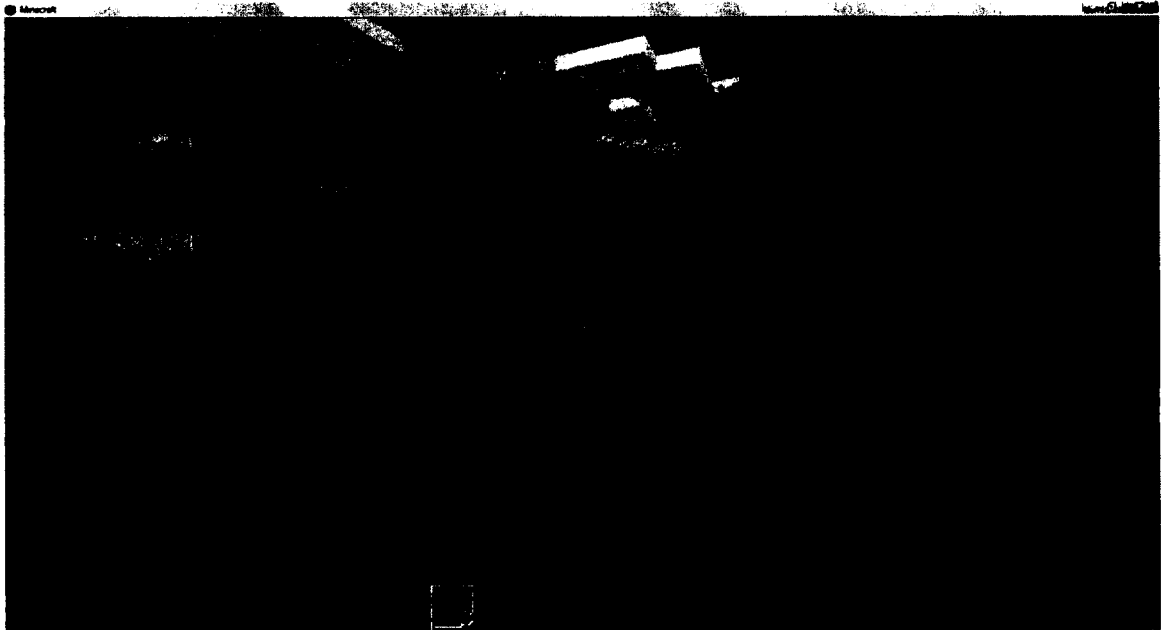


Fig. 30. Minecraft, by Mojang Studios [105]

Minecraft is another first person shooter which challenged the norm of what a first person shooter game should be. While many popular first person games, such as Electronic Art's Battlefield series pushed hyperrealism their presentation, seeking to draw the user into ever more immersive experiences, Mojang took the opposite approach. Minecraft is a very simple game in appearance. The innovation for Minecraft is that unlike most games in the shooter genre, the world is entirely deformable, and is technically infinite. The player can go anywhere they like and destroy or create anything they like.

There is some consistency within the game genres, but it is important to keep in mind that over time, innovative game designer will continue to push the boundaries of the genres, either by combining them into new hybrids or by developing entire new game types that defy easy classification. The observations of genres in this section hold true for many games, but it should not be surprising, as with any artistic field, to see games that defy the established norms and conventions. Serious games designers should head the challenges posed by the conventions of the genres, but not be afraid to develop innovative games that cross these lines.

6.2.4 Determine Learner's Social Interactions

Another important consideration is whether learners will be able to interact with each other in the game environment. This step of the design process is specifically concerned with how the players interact with each other, rather than how they interact with the game or the learning content. It is perfectly acceptable to not create any sort of interaction between the players. In game parlance, this would be a single player game, and even in the modern “connected” technology world, tends to still be a popular play style. Additionally, single player games tend to be more in line with Juul's categorization of casual games. Single player games tend to have a lower pressure threshold and are much more “interruptible”, as there is no social repercussion to “pausing” the game. Indeed, failure in single player games can also be viewed as less punishing, as other peers are not witness to a learner's stumbles and challenges within the game context, or possibly even depending on the learner to perform well in a multiplayer context. This makes single player games attractive for serious games targeted towards novices.

At the opposite end of the interactivity spectrum are fully interactive or multiplayer gamers. The sooner the determination is made to embark on creating a multiplayer game, the better, as such games require extensive networking architecture to support the desired interactivity. Such games may allow learners to cooperate or compete within the game environment in a manner which enhances the exploration of the learning content. For the same reasons as discussed with single player games, such games add a distinct layer of complexity, which should be considered in conjunction with the expected level of learner expertise.

One important challenge to recognize in developing multiplayer serious games is the requirement for the game to remain self encapsulated. As discussed in Chapter 2, there is a tendency for multiplayer serious game, especially in training contexts, to devolve into simple sandbox tools. If the game does not internally provide the goals and challenges, then it has lost important characteristics which define it as a game. If that occurs, the “game” is reduced to little more than a sophisticated chalk board. It may be useful for learning or training purposes, but without these components it now requires additional overhead, usually in the form of instructors or training facilitators, to be an effective learning tool.

As demonstrated by Element Solitaire©, there also exists a middle road for interaction, which harnesses aspects of both the single player and multiplayer game. This middle road provides indirect multiplayer interaction, most commonly enacted through competitive score or leader boards. In this game type, the actual game play is almost exactly the same as it would be in traditional single player mode. Learners have no interaction with each other when playing. However, the results of their performance are

recorded on a networked score boards. Though the players don't directly interact in the game, they can see and compare performance within the game. This allows the player to experience the content individually, yet still creates a degree of personal accountability, and ideally imparts added motivation for performance.

As shown in the experiment detailed in Chapters 3 and 4, there may be some intricate interactions occurring when players are put into competitive situation. It may be beneficial to keep in mind the internal and external motivational influences that a competitive game atmosphere might create.

6.2.5 Goals, Rules and Challenges

At this point in the serious game development process, the fundamental framework for a serious game has been established, and it is time to begin building the game itself. Returning to the analytic definition of what a game is, the participants have been defined in the previous sections, and what remains is to develop the goals, rules, and challenges the players will contend with.

It is important to differentiate the goals, rules, and challenges of the game from those of the learning content. The ultimate goal of the serious game is to produce a desired learning outcome, but this is not necessarily the same thing as the player's goal within the context of the game. The player's in-game goal will relate to resolving the challenges presented within the game, while their out of game goal will be to learn the desired content. If the two types of goals are meshed together well, the resolution of the game goal becomes the means by which the learning goal is achieved.

Development of a game play itself, however, is hard or perhaps even impractical to reduce to a rote procedure. Even though the process being proposed here focuses on determining the goals, rules, and challenges of a game, trying to create these aspects of a game in a clinical fashion is not recommended. Many entertainment game development processes, such as those described by Schell [19], Salen and Zimmerman [20], Crawford [16, 17], Dille and Platten [106], and Rollings and Adams [107], all seem to avoid trying to impose a mechanistic order on the creation process. Instead, they focus on finding sources of inspiration that serve as the genesis of a game, and then expanding that central idea into a full-fledged game. These published works offer a wide breadth of examples drawn from game industry professionals. They delve into the various and unique ways in which game seeds are grown into full products. The important distinction to bear in mind, when using these processes to create a serious game, is that there already exists a framework around the game that heavily shapes its development.

Indeed, the framework will likely provide the seed of inspiration, or play heavily into shaping it. The basic game concept may come from the learning content itself, or from genres suggested by the learning content. Typically genres tend to follow noticeable template, which can mesh with learning content to present a basic game concept. This nascent concept is then fleshed out into a full game.

Once the concept is fleshed out, however, it is worth returning afterwards to examine the goals, rules and challenges of the game. First off, it is important to ensure that they are present. When developing serious games, as mentioned previously, it is easy to slip into making a learning tool, rather than a learning game. Examining the goals, rules, and challenges is a quick and simple way to assess this concern. Digital

learning tools are valuable in their own right, and making such a tool is not wrong, per se, but it also is not the same thing as developing a complete serious game.

While fleshing out the game, it is also worth examining instructional design theories, such as Gagne's Conditions of Learning [108], Keller's ARCS Model of Motivation [109], Morrison's Instructional Strategies [78], or even Amory's Game Object Model [110]. Indeed, it is possible to see informal application of these strategies in many games designed purely for entertainment. Application of the rule-example instructional strategies can be seen in real time strategy games, such as the Starcraft series by Blizzard [94], or the Command and Conquer series [111], use rule-example instructional strategies to teach players how to play the game. Similarly, the first person shooter / puzzle game Portal, by Valve Software, uses interactive scenes to teach the player how to use artifacts within the game world [104]. These instructional design theories can easily be applied to help deliver the learning content within the game context.

6.2.6 Verify the Synthetic Propositions

The last step in developing a serious game should be to assess the product against synthetic propositions for a serious game. The serious game should:

- Have a variety of meaningful choices
- Be self encapsulated
- Be intrinsically compelling

It is worth reiterating that though these synthetic propositions are not fundamental to the definition of a game, they are helpful considerations in developing serious games.

Counter examples may present themselves, but these points are worth examining and reflecting upon their impact on the learning process.

In entertainment video games, there are many examples of fun and successful games that provide very little in the way of meaningful choices. A prime example is the popular music rhythm genre of games, such as Guitar Hero by RedOctane [84].

However, in the context of a serious game, the role of meaningful choices gains added importance. When following the examples of entertainment game design, it is important to examine which mechanics might limit or restrict the choices available to players. For example, one common mechanic frequently used to add tension and challenge to games is the time limit. Time limits are used to great effect in classic games like Super Mario Bros [26]. However, doing so also focuses the player on achieving a goal as quickly as possible, and may prevent them from fully interacting with learning content within the learning space.

A lack of choice may result from too closely emulating entertainment games. The opposite extreme, evidenced by a lack of self encapsulation or the absence of intrinsically compelling qualities within a game, may stem from being too little like an entertainment game. The encapsulation of the game is mostly be addressed by ensuring that the game itself presents the learner with the rules, goals and challenges. The process of making a game intrinsically compelling is a little more enigmatic. The relationship between engagement and education should not be viewed as a zero sum equation. The right kind of engagement fosters productive interactions with the learning content, and helps keep the learner focused.

6.2.7 Additional Considerations

In line with the consideration of whether a game should be creating the casual or traditional game mold, there is also a consideration of the balance between the effort required to enact certain game concepts and the learning payoff it will produce. Video game development has grown significantly since its inception in the 1970s and 1980s, when solitary programmers were developing games by themselves for early dedicated video game systems like the Atari 2600 [112]. More than three decades later, game development efforts have swollen to become massive enterprises. In 2008, the producer of Grand Theft Auto 4 stated in an interview that the game had cost approximately \$100 million to develop, and had around 1,000 people involved in its development [113]. Clearly, not all games are developed on the scale of Grand Theft Auto 4. Software developers unwilling or unable to compete on that level are still able to achieve enormous success by developing casual style games [114]. By 2011, Rovio games has distributed over 200 million copies of its downloadable game Angry Birds over a variety of mobile platforms, including smart phones and tablet computers [115]. While games from the Angry Birds franchise typically cost the consumer around three to four dollars, and therefore do not generate the individual profit per unit that a sixty dollar game like Grand Theft Auto does, it is also important to note that Angry Birds was developed by a team of 12 people [116]. In this regard, the profit to expense ratio is potentially much higher for a game like Angry Birds.

Similarly, serious games developers must take into account the reasonable effort they are willing and able to expend to create the serious game in question. There are a few some serious game endeavors that begin to approach a scale comparable to

commercial game development. For example, America's Army has been reported to spend \$32.8 million in development over ten years [117]. However, many serious games will not have this budget or this time frame for development. Even for those that do, it is also worth considering if such expenses are needed. For example, the cost in time, effort and money to develop a 3D game versus a 2D game can increase dramatically, and the payoff may not be worth the effort. Indeed, 3D games inherently add a degree of complexity to the content which the player is trying to learn. It may be undesirable for certain learning content or target learners. Whether in terms of graphic presentation or in terms of game mechanics, serious game developers should recognize when a simplified game will suffice for the learning purposes.

6.3 Case Study of Developed Games

Games, and by proxy, serious games, can take many forms. The theoretical work above provides specific variables by which the panoply of games can be organized, thus aiding in understanding them. These variables include where content is embedded (mechanics or aesthetics), learning content categorization (procedural or declarative), learner experience level (expert or novice), and the number of operative actions given to the player (many or few). These variables are organized into the variable interaction chart shown in Fig. 31. This chart shows all 16 possible combinations of these variables, and begins to provide a means of contextualizing an individual game in relationship to other serious games.

As discussed in Chapter 5, existing research has shown that either giving novice learner too many actions (high complexity) or giving expert learners too few actions (low

complexity) diminishes the respective learning outcomes [74, 75, 77]. Those research efforts involved chemistry simulation programs which focused on the mechanics of the learning content, and are reflected in the first column of the interaction chart. The portions of the chart shown in green, in the third column, run contrary to established instructional design heuristics [71]. That section reflects attempting to embed procedural knowledge (such as rules and principles) into the aesthetics of a game, where the player would interact with them only through repeated exposition to the aesthetics. That form of content presentation does not allow the user to exercise the principles or rules within the mechanics of the game.

Because of the added complexity and development burden incumbent in developing learning content for experts, this research will focus on the upper two rows of the interaction chart. Similarly, though the research by Park, et al., and Lee, et al., focused on the combination of embedding procedural knowledge into the mechanics of a game, it seems reasonable to generalize their conclusions and avoid trying to develop serious games which provide novice users with many actions [74, 77]. Accordingly, the remaining locations on the interaction chart are the intersection of games intended to teach declarative content to novice learners by embedding the learning content into either the game's mechanics or aesthetics. Element Solitaire fits the requirement for embedding the content via aesthetics, as the mechanics of drawing cards have little to do with the periodic table.

Content Embedding and Learning Content Categorization

		Mechanics Procedural	Mechanics Declarative	Aesthetics Procedural	Aesthetics Declarative
Learner Level and Number of Operative Actions	Novice Many Actions				
	Novice Few Actions	Park, Lea Messi	Limited Designs	Not recommended (Morrisson)	Element Solitaire
	Expert Many Actions				
	Expert Few Actions				

Fig. 31. Variable Interaction Chart

The serious game design process presented above has been developed primarily as a result of research into the nature of serious games and development experiences during the creation of Element Solitaire. However, Element Solitaire occupies only one portion of the chart shown in Fig. 31. During the course of this research two additional serious game prototypes were created to explore the application of the serious game design process to their development. Due to the intensive nature of creating a complete game, these design efforts were limited in scope, with the intent to produce a working prototype and initial design concept for each game, based on the proposed process.

6.3.1 Lewis Dot Challenge

The first of these design efforts was a game entitled Lewis Dot Challenge. First of all, the learning content for this serious game is the interaction of valence electrons between atoms. During the development of Element Solitaire©, several educational subject matter experts mentioned that this particular learning content would be very useful in high school and even introductory undergraduate college chemistry curricula. These requests fulfilled the first step of the Serious Game Design process; define and classify the learning content. The learning content is the creation of a Lewis Dot Diagram, and the content is primarily declarative, though it does start to move down the spectrum of towards procedural knowledge, using the categorization described above. The learners will be novices with the subject matter, as per step two of the process.

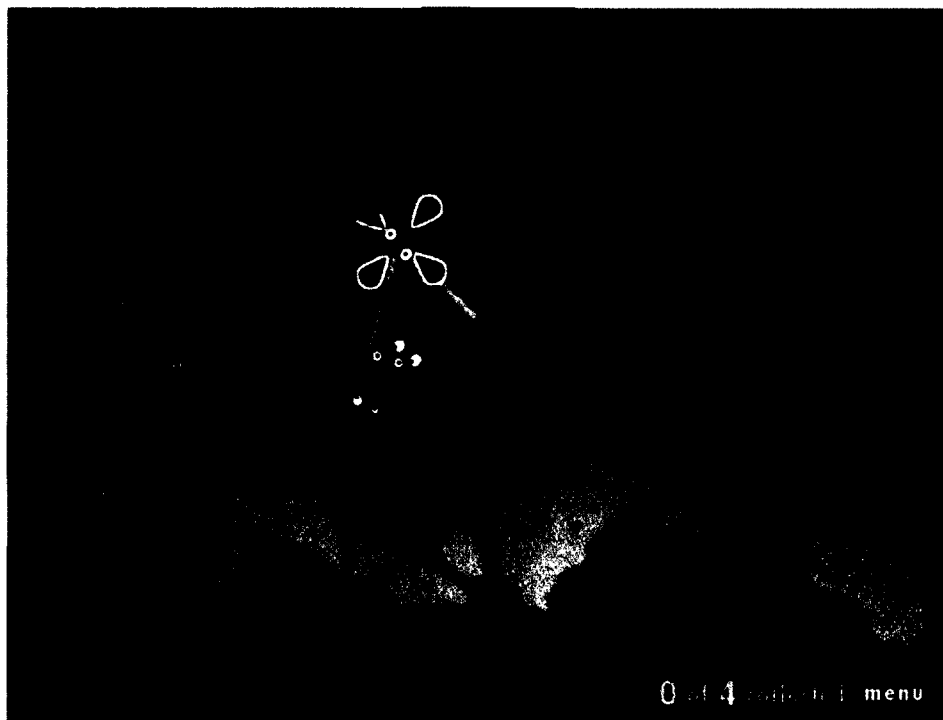


Fig. 32. World of Goo, by 2D Boy [118]

For step three, selecting the genre, the game was inspired conceptually by a popular casual puzzle game called World of Goo [118]. World of Goo is a 2D physics based puzzle game, in which the player is challenged to create structures from elastic goo balls which obey simple physics laws. The player pushes and pulls the goo balls into position and tries to overcome obstacles in each level.

The idea of positioning the elements of the game and having them form bonds seemed very congruent with the procedure for creating Lewis Dot Diagrams. Lewis Dot Diagrams are used to show the electron bonds between atoms in a given molecule, and are created using fairly standard procedures for assigning valence electrons to the atoms, and then forming the electron bonds between them. The initial storyboard for the game is a very simple electronic representation of the process, shown in Fig. 33.

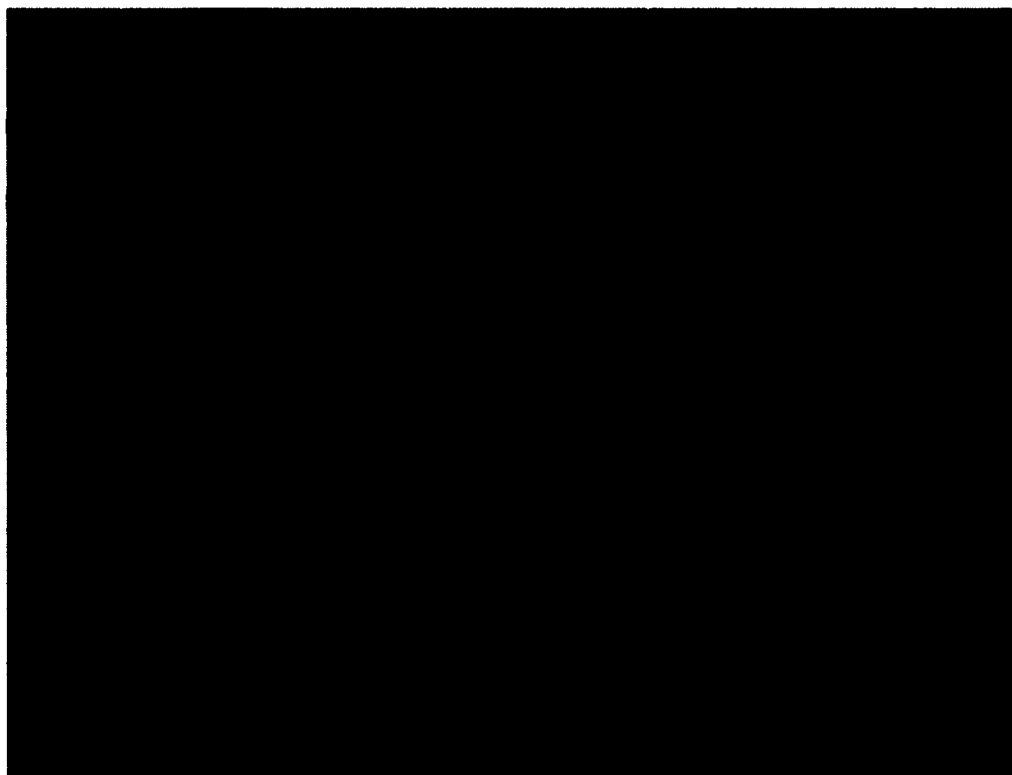


Fig. 33. Lewis Dot Diagram Storyboard

The interactions for the game, as appropriate for the learner expertise level, were meant to be very simple. The user would be shown the formula for the molecule they are diagramming at the top of the screen. On the left hand side they will have “atom dispensers” from which they can click and drag out molecules. On the right hand side of the screen are the electron configuration dispensers. These icons are used for the player to select the appropriate number of electrons for each atom. The electrons, like the atoms themselves, are dragged from the dispensers and dropped onto the appropriate atoms. If mistakes are made, then the individual atoms can be simply thrown into the wastebasket, and the player can start with new ones.

The goals for the game are to create the proper diagram for a given molecule. The rules are direct translations of the procedural learning content; the player must select the appropriate number of electrons per atom, the atoms must be arranged properly, and the covalent bonds must be formed in accordance with rules for creating a Lewis Structure. Fig. 34 shows the working prototype for the game in the process of creating a C_2H_4 ethylene molecule.

The last step of the process is to verify that the game is consistent with the synthetic propositions; that it has an appropriate selection of choices for the user, that it is self-encapsulated, and that it is intrinsically compelling. The number of choices provided to the player is consistent with existing instruction of Lewis Dot Structures, and should therefore be appropriate for the target learner audience. The breadth of the available choices within the game is relatively narrow, as is recommended for novice learners. The learner must select the correct ratio of atoms, select the right valence electron configuration for each atom, and properly create the appropriate electron bonds. The

game is self encapsulated; the user is presented with a series of puzzles in the form of a molecular formula, and then is given feedback upon completion of the Lewis Structure on any errors they have made. In the prototype form, however, the game may stumble in the area of being intrinsically compelling.

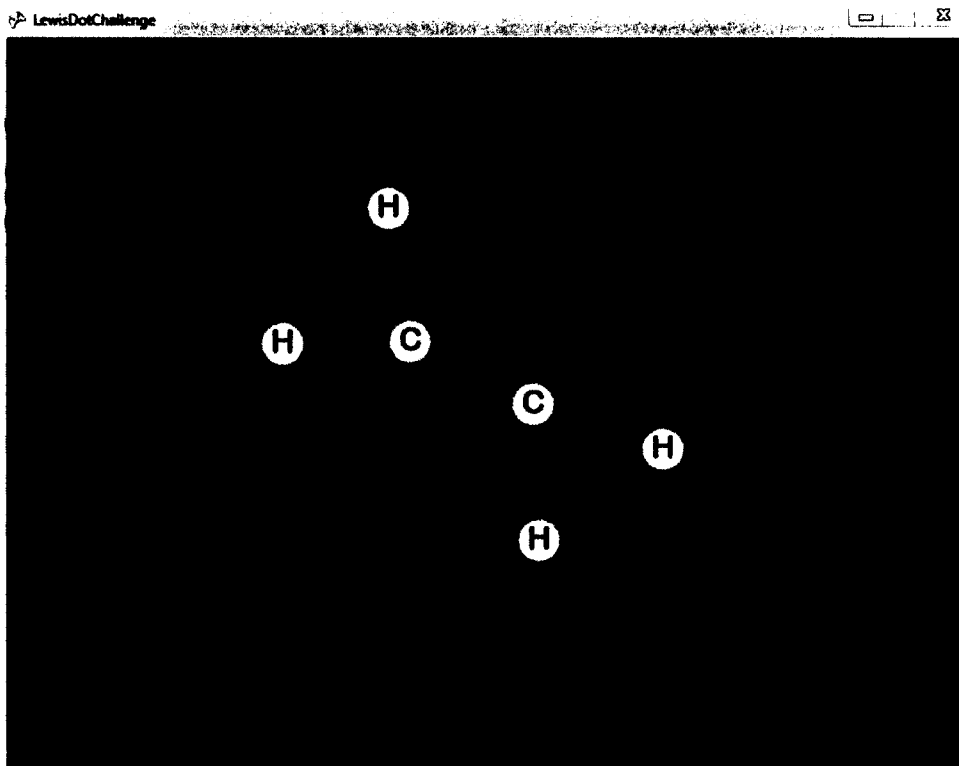


Fig. 34. Lewis Dot Challenge Prototype

One compelling aspect of World of Goo is the cute nature of the goo balls. They have cartoon like eyes and make small chirps and excited “Wee!” noises throughout the game. During the prototype development, the inclusion of small sound effects when the atoms or electrons were manipulated seemed to have a similar effect, making the process more compelling to engage in. However, the overall aesthetic presentation is still a bit lacking. The addition of enhanced graphics, balanced with the need to clearly

convey important education information would likely greatly make the game more compelling. Similarly, the game is fairly basic in terms of goals. Added challenge and interest could potentially be created by having more sophisticated goals. In World of Goo, the user has to apply the game physics to best obstacles on each level. Perhaps in Lewis Dot Challenge, similar higher level goals could be created. The player may have to choose the best configuration to create based on the number of atoms given. Or they might have to match the resultant structure shape to certain requirements on a given game level. The goal in such further development of this concept would be to utilize the procedural learning content to form the basic rules of the game. In this way, as the players are solving the challenges presented to them by the game, they have to use and understand the learning content.

6.3.2 ChemShooter 3D

The second prototyping design effort was based loosely on the space shooter genre of games, such as the classic games Galaga or even Space Invaders. This genre is sometimes referred to as SHMUPS (Shoot 'em ups). The idea was to employ the same sorts of interactions as are present in the Lewis Dot Challenge game, but to overlay the procedural learning content of molecular structure on a more traditional and recognizable video game formula. The first two Serious Game Design process steps were very similar to those from the Lewis Dot Challenge. The learning content for this game is the number of valence electrons for a neutral atom, and the ways in which these atoms combine.

The third step, alluded to above, was the selection of the SHMUP action/shooter genre of games. It is worth noting that for both of these games, the game concepts began

to crystallize when inspiration was drawn from an existing game. This might seem to indicate that the selection of game genre precedes the selection of the learning content, but the opposite is true. In each case, the learning content was identified first – via external input from educators in the chemistry field. But the learning content on its own does not always suggest a clear game concept. If a developer is armed with an understanding of what learning content they are trying to convey, then they can identify suitable game genres or concepts that lend themselves to conveying that content to the player. It is entirely possible certain genres or subgenres are ill suited to teaching certain materials.

Step four was to determine the user interactions within the game. As the knowledge content is more procedural for ChemShooter 3D, it becomes more important that the user's interactions are consistent with the learning content. The learning content had to be embedded in the mechanics that govern the game. The general game concept was that the player would have to selectively shoot specific targets according to descriptive features of the element they represent, such as family, series, or period. The controls for this game were chosen to be fairly consistent with the SHMUP genre, with the appropriate alterations. The player controls a space ship from the third person perspective. They can maneuver the ship around the screen, and then shoot at their targets (the atoms). If the atoms collide with the ship, then they cause damage, and if the player is not careful or does not properly shoot the atoms, then the atoms might destroy the ship. Fig. 35 shows an initial prototype of the Chemistry Shooter game.

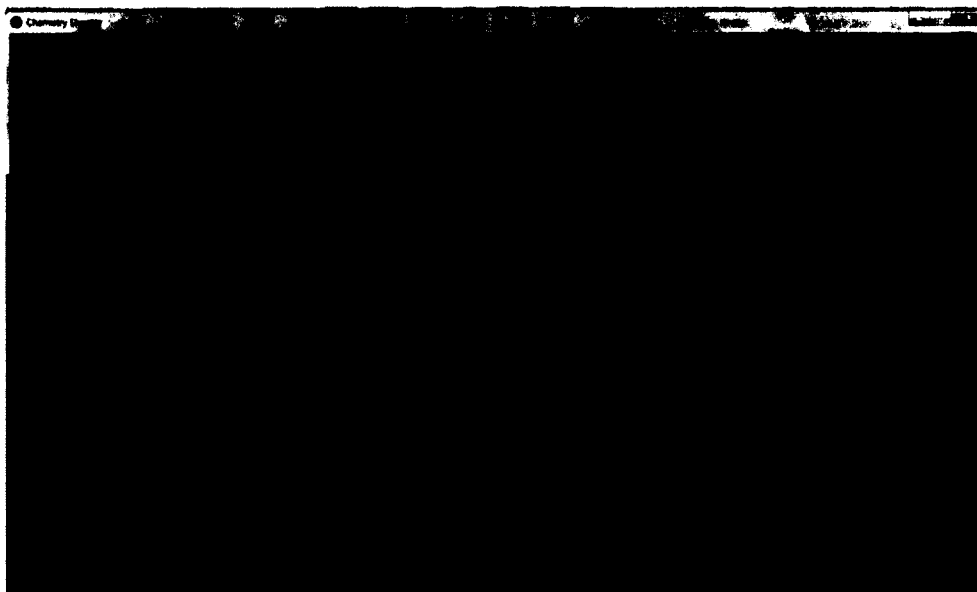


Fig. 35. Chemistry Shooter Screenshot

These interactions lend themselves to the development of the game's goals, rules, and challenges, which is step five of the serious game design process. Over time, the player interactions became more specific, shaped in part by the development of the Lewis Dot Challenge. First the decision was made to make the game in 3D, and second the decision was made to allow the user to "build" electron configurations by "loading" a certain number of shots to shoot at each element. The number of electrons in a shot would need to match the appropriate number of valence electrons in a neutral atom, thereby neutralizing the atoms. If the player collides with an "unstable" atom that has not been neutralized, then they take damage, but they can safely collide with neutralized atoms. Further, erroneous shots with the wrong number of electrons for a given atom will increase their speed, making them harder to avoid. The atoms bounce around within the defined play space. Once all the atoms are neutralized, then the player has successfully completed a level. Fig. 36 shows the storyboard for this development of the

ChemShooter 3D development process, and Fig. 37 shows the working prototype of the game.

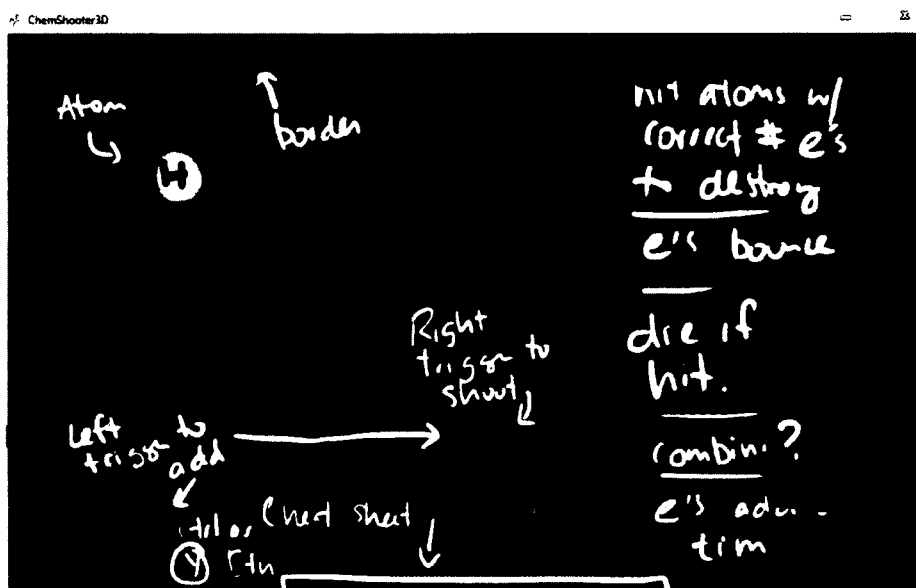


Fig. 36. ChemShooter 3D Storyboard



Fig. 37. ChemShooter 3D Prototype 2

In Fig. 37, two of the Helium atoms are neutralized, as shown by the 3D atoms (blue spheres) circling them, and the player has “loaded” two electrons to fire at the remaining atom. Of course, more challenging levels could include a variety of atoms, each from different elemental groups, forcing the player to be more discriminating in the number of electrons fired at each atom. These interactions formed the goals, rules, and challenges. The goal is to neutralize all the elements on the screen. The rules are that: the element must be neutralized by the appropriate number of electrons, the inappropriate number of electrons will make them move faster, and collision with the unstable electrons will damage, ultimately destroying the player’s ship.

The last step of the design process is to verify that the game has an appropriate variety of choices, is self encapsulated, and is intrinsically compelling. As with the Lewis Dot Challenge game, ChemShooter 3D is intrinsically self encapsulated. The player is given immediate feedback when they try to apply the incorrect number of electrons to an atom. It also has an appropriate number of choices for a novice player who is just learning about the relationship between valence electrons and periodic table groups. The game has the potential to be intrinsically compelling as a function of the art, sound effects, and challenge of the game. Additional challenge and learning content could be added by requiring the player to form molecules according to specified formulas as in the Lewis Dot Challenge game. In this mode, the “neutralized” atoms could still cause collision damage, requiring the player to “catch” them and join them with the other atoms in order to complete a level by forming specified molecules.

6.4 Additional Possible Designs for Periodic Table Content

As a further exercise of the Serious Game Design process, and a further examination of the interaction between video game genres and learning content, the following section offers a brief conceptual examination of the remaining game genres in the context of developing a chemistry-oriented serious game. The learning content and target audience for these game ideas will remain the same. They will deal with the valence electron configurations and the bonds formed between atoms within a molecule, and they will be targeted towards novice learners. The prototyped games, Lewis Dot Challenge and ChemShooter 3D covered the Action and Family / Puzzle / Casual genres, while the remaining genres are discussed below.

6.4.1 Sports Games

The sports genre is a difficult one to adapt to diverse learning contents unless the concept of sports is very loosely interpreted. The challenge is that established sports have definite established rules and mechanics, and it might be challenging to adapt these to the desired learning content. However, if the concept of 'sports' is taken very freely, or the sports are abstracted, then it may be possible to combine the two.

One approach may be to consider that each player on a sports team has different attributes. The different attributes of the atoms could be similarly taken as metaphors for the physical performance of the players on the sports team. In this regard, the player may have to see the "playing field," and assign available atoms and or electrons in the proper configuration to achieve the best outcome.

There is a danger that this sort of interpretation can be taken to far, to the point where the game becomes more of a puzzle than sport. To this end, it may be helpful to include some form of motor-control / manual dexterity play in the game. Perhaps the player sets up the team to run a play in a football type game, where one team is the atoms, and the opposing team is the correspondent electron configurations. However, once the player has established how the “team members” are organized, they still take direct control of some aspect of the action while the team runs its course. As discussed previously, this genre does not appear to be one that readily lends itself to teaching chemistry, but the successful development of an innovative game that does push the boundaries of the genre could be very rewarding.

6.4.2 Racing Games

As with sports games, racing games tend to be fairly strict in their implementation. The player typically takes the part of a driver of a vehicle of some sort or another, and interacts by steering, accelerating and braking the vehicles. These particular mechanics don't appear to lend themselves directly to the desired learning content, but it may be possible, again, to apply them in an abstract form.

A type of racing game could be created where the speed of the player could be a function of how quickly they can solve Lewis Dot Diagrams. For, each step performed correctly, or each molecule created correctly, then the player's car may move a certain distance. This concept has the same potential danger as the sports concept described above, in that it essentially defaults to a puzzle style game. Again, it may be possible to include a real time, motor control and reflex portion of the game. Perhaps the player

“charges up” their vehicle for the race by creating Lewis Dot structures within a limited amount of time, and then actually control the vehicle with the resultant performance parameters based on their level of success. It is worth noting that the disconnect between the genre norms in the racing and sports games don’t preclude the possibility of creating a game on the chemistry learning content, but they do create an increased level of disconnect between the core game mechanics and the learning content.

6.4.3 Adventure Games

The adventure genre seems to be a mid-point between puzzle games and role-playing games. These games typically pit the player into the role of the protagonist, but the game play trends towards a series of puzzles being solved within the context of the endogenous fantasy. Characteristically, the fantasy in adventure games tends to be a lot more flexible than in a role playing game, as the game effectively is a vehicle for transporting the player between various contextualized puzzles, strung together by a loose narrative.

As such, it would easy to create an adventure by which the player moves from puzzle to puzzle, having to solve various challenges based on the principles of valence electrons and molecular bonds. Additionally, these types of game have the advantage of casting the learner into the role of a specific protagonist. Gee posits that this sort of identification process can create positive affect within the learners, which can be very effective in conveying the material to novice learners [4].

6.4.4 Strategy Games

The Strategy genre is a wide open palette, similar in many ways to puzzle games. It is possible to overlay a wide variety of mechanics and dynamics upon a strategy game, making it a good candidate for integration with learning content. The key difference between puzzle and strategy games is that strategy games tend to be more competitive in nature. The players interact with the game world via set rules, but their goal is typically to overcome or outperform a competitor. The competitor might be another player or the computer, but either way, the competitor typically is an active opponent to the learner, within the context of the game.

A strategy game for the “valence electron and molecular bond” learning content might resemble, in many ways the dynamics described for the sports genres. The player might array certain molecules, atoms, or electrons so that they behave in specific ways, according to their periodic table characteristics. With strategy games, there is less of an expectation of direct control, so it might be more desirable for the player to maintain a detached third person view, controlling all of their available assets as they try to achieve a goal.

6.4.5 Role Playing Games

Like adventure games, role-playing games provide a great opportunity to cast the learner into a desirable role of proactive learner or even subject matter expert within the context of the learning content. The challenge with creating an effective role-playing game is that these types of games tend to be very content and, as discussed, narrative heavy. If done well, this can result in very deep and compelling gameplay experience.

However, the challenge arises when trying to specifically integrate the learning content with the game mechanics. The techniques described above could be employed to create similar gameplay mechanics, but there is an additional burden in making the game mechanics consistent with the learning material and the game narrative or fantasy.

6.4.6 Fighting Games

Lastly, the Fighting genre has the same challenges as the Sports and Racing genres. These games all have strongly associated norms, in terms of control and mechanics. It is challenging to try and integrate these existing mechanics with the mechanics of the intended procedural learning content. Abstract interpretations of the genre can allow for some liberty to be taken in how the integration takes place, but the bar is set pretty high for these types of games. In order to create effective and engaging games, the serious game creators would have to be very innovative in their design.

6.5 Comparison of Some Existing Serious Games

The Serious Games Classification database lists nine educational games with the key word “chemistry” [102]. The games are broken down into four puzzle games, four adventure games, and one action game. In general, these games are fairly consistent with the principles embodied in the proposed Serious Game Design Process.

The puzzle games include Foldit [119], School House: 30 Educational Games[120], Elemental, and Terraform [121]. Elemental appears to be a Tetris style game, in which block of elements are stacked on top of each other. Unfortunately, this is a Flash game which appears to be no longer available. Similarly, School House is a

collection of puzzle style games from a variety of subjects, published in 1991, and is also no longer available. Terraform is described as a puzzle / exploration game, created for the 2010 I/ITSEC Serious Games Showcase and Challenge. It is presented from the first person point of view, and allows the player to combine compounds in to various chemicals to help Terraform a planet. Lastly, but perhaps most significantly, is the game Foldit [122].

Foldit is a game which challenges players to create the most effective protein structures. The biochemical rules which govern the shapes of proteins make up the rules and challenge of this game. According to these rules, players are ranked by how effective their protein structure is. In 2011, Foldit made headlines when players from the game, many with little or no formal biochemical training, unraveled the structure of a key enzyme in the Human Immunodeficiency Virus (HIV) [123]. The video game players effectively solved a problem that had stymied researchers for ten years.

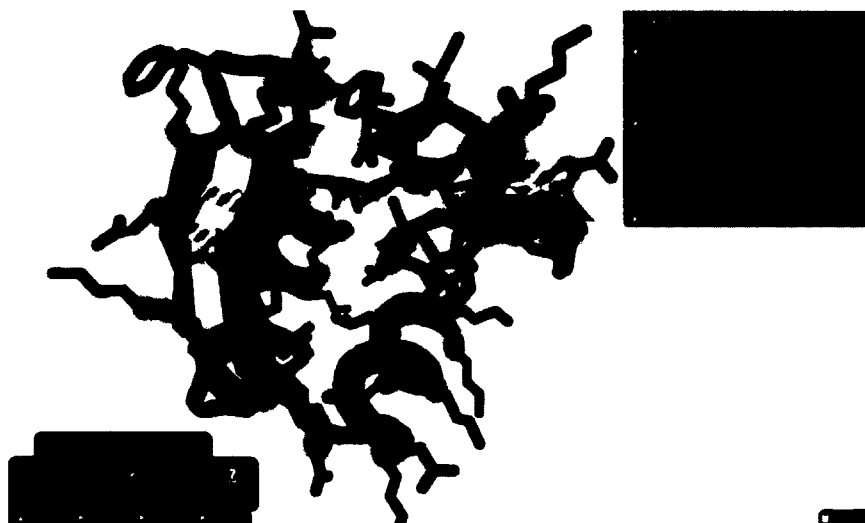


Fig. 38. Foldit, by the Center for Game Science at University of Washington [119]

The adventure games consist of ChemRacer 2713: The Legend of Kid Chem [124], Compound Reaction [125], Chemicus: Journey to the Other Side[126], and Afterzoom [127]. ChemRacer, in spite of its name, is presented as more of a top view adventure game, where the player uses their mouse to move a car around the screen from an overhead view. When the player collides with objects, they are asked to identify various elements. Compound Reaction is a combination of third and first person perspective game that allows the player to explore a deserted planet, and transition to third person space ship shooter type puzzles to assemble various chemical elements. The third person space ship sequences appear to be conceptually similar to ChemShooter3D. Compound Reaction was also an entry in the I/ITSEC 2008 Serious Game Showcase and Challenge. Chemicus is presented as a puzzle adventure game in the style of Myst. The player moves from location to location in the city of Chemicus, and must solve Chemistry based puzzles to return home. Lastly, Afterzoom is a downloadable game for the Nintendo DS series of handheld consoles. The game makes innovative use of the DS camera to create a form of augmented reality adventure. The player can “zoom in” on different surfaces to catch the microscopic creatures which the game presents to them. The creatures are raised and trained by feeding them various chemical elements, and the elements give the creatures different attributes based on their atomic properties. The game seems to draw inspiration in part from the popular game series Pokemon.

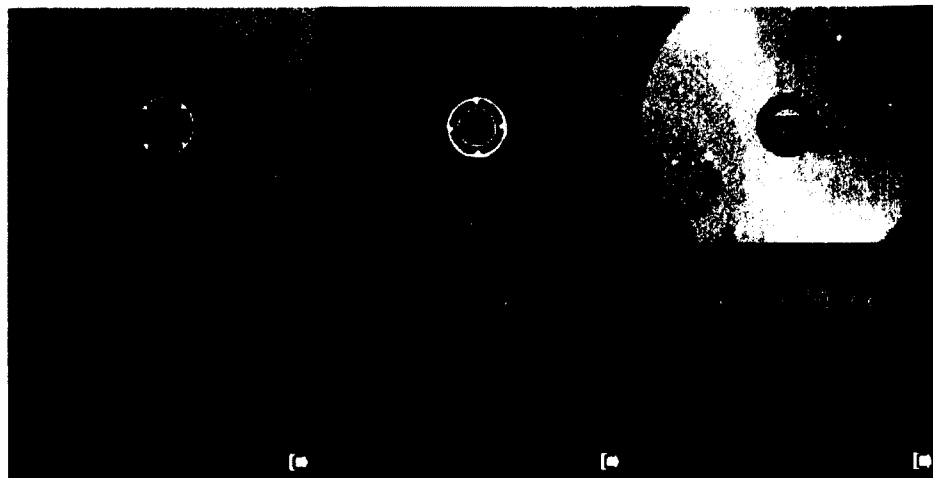


Fig. 39. Afterzoom, by Abylight [127]

The last game is the action game MeChem [128]. MeChem is a multiplayer online giant robot game, controlled from the third person perspective. Players build their robot from different chemical elements, and the element used gives the robot different attributes. The game is unique in that you can only play online when other players are present, and the game has a mechanism to track which school each player is from, allowing them to play against each other. This game highlights one of the pitfalls of multiplayer games, specifically with regards to the self encapsulation proposition. The game can only be played against another player, so unless someone else is playing at the same time, you are unable to utilize it.



Fig. 40. MeChem, by David Nikdel [128]

In the design and implementation of these games, many of the same challenges identified in Section 6.4 can be seen at play. The ChemRacer game, may, by its name, have been intended to be a racer game, but the Racing genre mechanics prove unsuited to support the chemistry learning content. As a result, the end game is an adventure that strings together a series of puzzles. Indeed, throughout the games, it is evident that at the heart of these games, the chemistry learning content is ultimately delivered through puzzle mechanism, regardless of the overall game genre. MeChem teaches chemistry through the puzzle of creating a robot. Chemicus tells an adventure story, but the learning content is interacted with via puzzles. Puzzles serve as an ideal vehicle through which the game designers can convey the learning content. In order to fulfill the expectations of the larger game genre, additional game content is added. In most cases,

however, this game content does not contain learning content. It may be no accident that the best regarded of these game, Foldit, is almost purely a puzzle game.

6.6 Summary of Game Design Principles and Processes

This chapter has proposed a comprehensive Serious Game Design Process based on the theoretical research presented in this dissertation as well as the empirical results from the experiment described in Chapter 3 and 4. The end result is a simple but effective set of design principles designed to incorporate the significant of the presented concepts. Once the process was developed, it was applied to the development of one complete serious game, two serious game prototypes. As demonstrated by the preceding analysis, this process can also be used as a lens through which to examine nine developed serious games.

CHAPTER 7

CONCLUSION

This chapter presents a summary of the findings and conclusions from the dissertation. It also describes a number of potential lines of research that directly relate to the results and products of this research.

7.1 Summary

This dissertation has presented three major contributions. The first is a practical clarification of the concept of serious games, within the context of the presented research question, as a tool of examining the impact that game design principles have upon learning outcomes. The concept of serious games was presented in two parts: the analytic and synthetic propositions. The analytic proposition held that games consist of:

- Participants
- Goals
- Rules
- Challenges

The synthetic proposition held that games, and serious games in particular, should:

- Be self encapsulated
- Have a variety of choices
- Be intrinsically compelling

Based on this conceptual framework, three hypotheses were derived to test the efficacy of the synthetic propositions. The hypotheses were that:

1. A serious game with meaningful choices will result in higher learning outcomes than an identical game without meaningful choices.
2. A serious game with competition will be more intrinsically compelling and result in higher learning outcomes than an identical one without competition.
3. A serious game with added aesthetic features, to include graphics and music, will be more intrinsically compelling and result in higher learning outcomes than an identical one without music and graphics.

These hypotheses were tested via a quantitative experiment involving over 200 undergraduate students in the Old Dominion University Chemistry Department. The experimental results demonstrated that the aesthetic presentation of a game can have a significant impact upon the learning outcome. The experiment was not able to discern significant effects from the choice or competition conditions, but further examination of the experimental data did reveal some insight into these aspects of serious game design. Choices need to provide the player with options that have a sufficient value that they will be considered and the application of competition within games needs to be judiciously implemented to promote a positive affect for all players.

The results of the theoretical foundations and empirical evidence were then combined with additional theoretical research to develop a set of design principles and a proposed Serious Game Development Process. These guidelines were researched and

examined via the design and development process of several serious game prototypes and the examination of a large body of existing serious games. The end result is a practical procedure that is rooted in theory and empirical research.

Proposed Serious Game Design Process

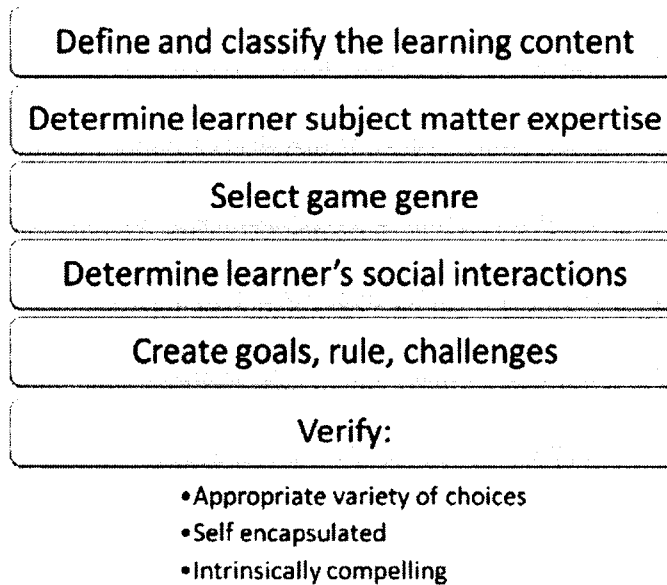


Fig. 41. Proposed Serious Game Design Process

7.2 Future Work

The empirical research and theoretical constructs presented in this work present new information that might contribute to the greater body of knowledge in the field of serious games, but it also raises some interesting questions that merit further exploration. This line of research appears to have a rich potential for further inquiry. The following section details some particular potential lines of research.

7.2.1 Aesthetic Presentation

The experimental results detailed in Chapter 4 provide strong evidence that, in the Element Solitaire© game, the aesthetic presentation had a significant impact on the learning outcome. As with any experimental research it would be useful to see independent verification of these outcomes. This poses certain challenges and questions. As discussed, the aesthetic presentation is largely a subjective endeavor, and the history of art criticism has indicated that such endeavors are very challenging to quantify [129-131].

One extension to look further into the results would be to separate the distinct components which went into (or were omitted) in the creation of Degraded Aesthetic treatment used in the experiment. Specifically, this treatment modified the following five aesthetic elements:

- Sound Effects (cards flipping and sparkle sounds for correctly placed elements)
- Music (including distinct songs for the menu and game portions of the program)
- Animation (card flipping animation, card movement animation)
- Sparkles (random particle effect triggered by a correct placement)
- Graphics (including the static graphics for the card back, menus, text, backgrounds, and title screen)

Since the combination of these aesthetic conditions has been shown to have an effect, it would be informative to repeat the experiment, under similar test conditions, while varying each of these five factors for each experimental group. Doing so may provide a clearer picture of which particular element from the aesthetic presentation had the most significant effect upon the learning outcome. This could be a very valuable piece of information, as serious game designers try to decide where to allocate limited resources in developing their games.

Similarly, it would be informative to expand scope of the aesthetic presentation. While the different conditions were shown to have a statistical impact, it may be beneficial to expand the scope of aesthetic options. Element Solitaire©, in all of its forms, was made using simple 2D sprites created by an amateur graphic design using simple graphical editing software tools. Even the Baseline (enhanced) graphics condition leaves much room for improvement. Many different levels of the aesthetic presentation could be created and tested to see if there is a linear effect between the quality of the aesthetics, and the learning outcomes, or if there is simply a threshold level of perceived quality which must be surpassed.

One problem that arises in the testing of an array of different aesthetic treatments is that the ability to discriminate or assess a qualitative value of these different treatments becomes much more challenging. A possible solution would be to validate the treatments within the context of the experiment. Participants could be asked to rate the aesthetic qualities of the various treatments. The ratings could then be correlated with the learning outcome.

Another slight variation on that validation model might be to take a constructivist approach and specifically examine each individual user's unique assessment of the aesthetic presentation. This approach, again, is consistent with the sentiment that the valuation of artistic endeavors, ultimately, may be somewhat consistent amount certain demographic groups, but is ultimately a very individual assessment [131].

Lastly, it might be informative to use electroencephalographic tools to examine the neuro-electrical response that participants have to the different aesthetic presentations. Such tools may be useful in determining if the aesthetic presentation does indeed, as supposed, serve as a barrier or enabler to the user engaging with the learning content.

7.2.2 User Choice

As mentioned in Chapter 4, the Choice condition of Element Solitaire© appears to have no significant effect upon the learning outcome of the participants. Chapter 4 proposes a specific game reformulation that would have a significant impact upon how the game is played. Currently, there is no way for the player to 'lose' the game, per se. Even if the player fails consistently, the effect is only to prolong the game. Once a player has selected a specific set of Elements to play with, they will have the opportunity to place all of them, until they are correct. When the player fails a placement, the only outcome is that their score will be lower. The reformulation in Chapter 4 would increase the penalty for failing to place an element by prematurely ending the game. For example, a player might have three "lives" and lose a life each time they have an errant placement. Thus, a game can be "won" by surviving to the end, and not losing all three lives.

The trade off with such a game style is that then a poor performing player might not be exposed to all of the learning content. If the player loses all their lives, they may never see the most challenging elements. The result, however, would be that the hints and skips would gain additional importance. If the player seeks to not “die”, the utility cost benefit calculation of paying a point penalty for a hint becomes very attractive in comparison to losing a life.

As choice falls under the broader proposed serious game design principle of “intrinsically compelling”, this proposed reformulation of the game could make a very interesting experimental condition. Effectively, it may make the game more challenging, and ultimately, induce the learner to play it in a much more conscientious manner. However, it also does pose the risk that low performing or unmotivated learners will not ever become exposed to the target learning material. Such a game design would likely require a different experimental structure. In the experiment, the experimental design, via the TEP wrapper, required the players to complete four games. If the learner is unmotivated, they are incentivized to intentionally fail the game in order to “complete” four games. It is likely that with this alternate condition, the experiment requirements would have to be altered so that the participants may have to “win” a certain number of games, regardless of how many times they play.

7.2.3 Competition

The competition results also highlighted some very interesting outcomes. As noted, the variation on the learning outcome was higher for the No Competition experimental group than for the other experimental groups. In retrospect, the No

Competition condition in fact was a Self Competition condition, as compared to a the Group Competition condition present in all the other treatments. The alternate presentation of the individual game scores suggests several additional experimental treatments that may be tested against each.

One such treatment might be a true No Competition treatment, which would simple not have a score board. In fact, this treatment could even be taken a step further and not even have a score board. Effectively, a score becomes a means of comparing an abstract measure of performance, and is ultimately a tool of comparing performance. The player would not be shown any score, and not be shown any scoreboards. This treatment may have some complex interactions with the current hint system.

Another treatment might be to combine both the group and individual score board. This way, the user can both see their individual progress, if they are internally motivated to improve their performance, as well as see their relative performance against their peers.

Lastly, the score board could be updated to include the relative performance of all players. During the experiment the Competition condition scoreboard only showed the scores for the top 10 players. Given that there were 172 players that completed the experiment, this meant that the vast majority did not see their performance reflected upon the score board. This alternate scoreboard could show a scrollable list, with all players appropriately ranked on it. Alternately, the players may be shown an individualized local score board. Perhaps the players are shown their score, as well as a certain number of players who scored both higher and lower than they did.

This wider variety of competition conditions could provide some interesting insight into how competition affects learners within serious games. It could also help guide serious game developers in determining what might be the most motivational presentation of competition for learners. Such a study may also benefit from additional assessment of participant personality traits, such as innate competitiveness.

7.2.4 Intrinsically Compelling

The design of the experiment, specifically the requirement for the participants to complete a specific number of game, created a confounding effect that prevented the data from being used to as a direct assessment of how intrinsically compelling the game, and in turn, each treatment, was. The data indicated some interesting potential trends, both in terms of the number of players who completed experiment, and in terms of how many times the game was played, but the complications in analyzing those trends prevent them from being scientifically sound.

It would be very interesting to see how the participants respond to the game, with its various conditions, freed from those experimental design constraints. Such an experimental design could be easily administered by simply eliminating the requirement that the participants play the specified number of games. This formulation does create an additional level of complexity to the analysis, as it would effectively create two dependent variables – the number of games played and the learning outcome.

7.2.5 Alternate Games

Another avenue of research is to explore more fully the breadth of the interactions between learning content categorization and game design. Element Solitaire© has few operative actions, and teaches declarative knowledge, primarily embedded in the game aesthetics, to novice learners. The prototyped games, Lewis Dot Challenge and ChemShooter 3D begin to explore the higher levels of knowledge content types by embedding procedural learning content into the game mechanics. It would be very informative to test games across the breadth of the interaction chart, shown again in Fig. 31. Specifically, given the experimental results from Element Solitaire©, it would be informative to see if the aesthetic presentation plays as important a role in learning outcome when the learning content is embedded in the game mechanics, and the aesthetics of the game are distinct from the learning content.

7.2.7 Game Platform

Lastly, it may be informative to explore the impact that game platform has on serious games. As noted in by Juul, video game play and expectations varies by platform [46]. A prime example of this is seen when comparing popular games on smart phones, such as Android, iOS, and Windows Phones, with the popular games on consoles, or with popular games on personal computers. Not only are the games popular, but level of expectation and ways in which players interact with the games are different as well. It would be beneficial to see if the differences elicited by the platforms have an effect on the learning outcome which players derive from the games.

APPENDICES

APPENDIX A: Institutional Review Board Exemption



1 October 2010

Dr. Youzhong Shen
Department of Modeling, Simulation,
and Visualization Engineering

Juergen Kolb
Human Subjects Research Committee

Your proposal: **A Serious Game about the Periodic Table**
Reference number: **10-003**

Your application for exempt research has been reviewed by the BCET Human Subjects Committee and was found to be exempt from IRB review under the Code of Regulations 45CFR46.101(b) for the following reason:

- Research is conducted in commonly accepted educational setting, involving normal practices;
- Subjects cannot be identified directly or through identifiers linked to subjects and disclosures of the subjects responses will not put the subject at risk of criminal or civil liability or be damaging to the subjects reputation.

Please contact the committee immediately if you wish to make any change to your proposal that might alter its exempt status.

I wish you good success with your research project.

Sincerely,

Juergen Kolb

ACADEMIC PROGRAMS

Aerospace Engineering
Civil Engineering
Civil Engineering Technology
Computer Engineering
Electrical Engineering
Electrical Engineering Technology
Engineering Management
Environmental Engineering
General Engineering Technologies
Mechanical Engineering
Mechanical Engineering Technology
Modeling & Simulation
Systems Engineering

ENTERPRISE CENTERS

Applied Research Center
Center for Advanced Engineering Environments
Langley Full-Scale Wind Tunnel
Mid-Atlantic Regional Spaceport
Virginia Applied Technology and Professional Development Center

INSTITUTES/DIVISIONS

Coastal Engineering
Engineering Fundamentals
Lean Institute
Multidisciplinary Parallel and Vector Computations
National Centers for Systems of Systems
Scientific and Educational Technology
Ship Maintenance, Repair and Operations
Sustainable Development

APPENDIX B: Pilot Study Consent Form

Informed Consent

Investigators: Michael Martin (mmart081@odu.edu)
 Department of Modeling, Simulation, and Visualization Engineering
 Frank Batten College of Engineering & Technology
 Old Dominion University

Yuzhong Shen (683- 6366)
 Department of Modeling, Simulation, and Visualization Engineering
 Frank Batten College of Engineering & Technology
 Old Dominion University

Title: A Serious Game about the Periodic Table

I, _____, hereby agree to participate as a volunteer in the above named research project "A Serious Game about the Periodic Table". I know that I will be asked to interact with a video game related to the Periodic Table of Elements, and provide written responses to associated study related material. Following the conclusion of the study I will obtain an explanation of the study and its purposes.

I understand that the information collected in this study will be kept confidential within the limits of the law.

I understand that at any time I am free to refuse to participate or answer any question without prejudice to me, that I am free to withdraw from the experiment at any time, and that Old Dominion University does not have any funds budgeted to compensate for injury, damages, or other expenses.

I understand that this study will last approximately between 0.5 and 2 cumulative hours over a period of one week. I understand that the written transcriptions from my participation in this study and digital records of my performance playing the respective video game may be analyzed by other credible researchers and that no personal identifying information will be preserved or associated with my participation in this study.

I understand that by agreeing to participate in this research and signing this form, I do not waive any of my legal rights.

Signature _____

User Name _____

Today's Date _____

APPENDIX C: Pilot Study Pre / Post Test

User Name: _____

Date: _____

Periodic Table of Elements

1. Place the correct element (from the bottom of the page) in each location.

2. Correctly write the element name for each symbol.

Al - _____	Co - _____	K - _____	O - _____
Ar - _____	Cr - _____	Kr - _____	P - _____
As - _____	Cu - _____	Li - _____	S - _____
B - _____	F - _____	Mg - _____	Sc - _____
Be - _____	Fe - _____	Mn - _____	Se - _____
Br - _____	Ga - _____	N - _____	Si - _____
C - _____	Ge - _____	Na - _____	Ti - _____
Ca - _____	H - _____	Ne - _____	V - _____
Cl - _____	He - _____	Ni - _____	Zn - _____

APPENDIX D: Pilot Study Survey

Demographic Survey

Please rate the following two questions according to how much you agree:

<p>If a player scored well on this game, it was because they knew the Periodic Table of Elements.</p>	<input type="radio"/> Strongly agree <input type="radio"/> Agree <input type="radio"/> Somewhat agree <input type="radio"/> Disagree <input type="radio"/> Strongly disagree
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<p>It is possible to get a high score in the game without knowing the Periodic Table of Elements well.</p>	<input type="radio"/> Strongly agree <input type="radio"/> Agree <input type="radio"/> Somewhat agree <input type="radio"/> Disagree <input type="radio"/> Strongly disagree
--	--

<p>How would you rate the useability of this program (i.e., how easy was the program to use?)</p>	<input type="radio"/> Easy to understand and use <input type="radio"/> A little bit confusing or hard to use <input type="radio"/> Very Hard to understand or use <input type="radio"/> Impossible to understand or use
---	--

<p>How would you rate the difficulty of the game <u>for you</u> (i.e., how challenging was the game?)</p>	<input type="radio"/> Too easy <input type="radio"/> Somewhat easy <input type="radio"/> Just right <input type="radio"/> Somewhat hard <input type="radio"/> Too hard
---	--

<p>How would you rate the difficulty of the game <u>for a non-chemistry major</u>?</p>	<input type="radio"/> Too easy <input type="radio"/> Somewhat easy <input type="radio"/> Just right <input type="radio"/> Somewhat hard <input type="radio"/> Too hard
--	--

<p>Did you ever use any external material to help out while playing this game?</p>	<input type="radio"/> Yes <input type="radio"/> No
--	---

Do you have any comments about the game (for example, problems encountered or recommendations for improvement?)

APPENDIX E: Example of Server Collected Performance Data

```
<PerformanceData>
  <name>Participant X</name>
  <score>12624</score>
  <timeStarted>2011-02-24T14:42:55</timeStarted>
  <timeFinished>2011-02-24T14:44:09</timeFinished>
  <numElementsMissed>1</numElementsMissed>
  <totalMissed>0</totalMissed>
  <skipsUsed>0</skipsUsed>
  <hintsUsed>0</hintsUsed>
  <missList>
    <Misses>
      <elementName>Magnesium</elementName>
      <timesMissed>1</timesMissed>
    </Misses>
  </missList>
  <size>89</size>
</PerformanceData>
```

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Old Dominion University Mail - Request for Zombie Division image use in dissertation



Request for Zombie Division image use in dissertation

Michael Martin <mmart081@odu.edu>
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Mon, Jun 18, 2012 at 1:23 PM

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Respectfully,
 Mike Martin
 Old Dominion University
 Modeling, Simulation, and Visualization Engineering
 mmart081@odu.edu

Habgood, Jacob <J.Habgood@shu.ac.uk>
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REFERENCES

- [1] M. Yi, "They Got Game," in *San Francisco Chronicle*, ed. San Francisco: Hearst Newspapers, 2004.
- [2] N. V. Zelfden. (2009). *What's Killing the Video-Game Business?* Available: http://www.slate.com/articles/technology/gaming/2009/02/whats_killing_the_video_game_business.single.html
- [3] M. Zyda, "From Visual Simulation to Virtual Reality to Games," *Computer*, p. 8, September 2005.
- [4] J. P. Gee, *What Video Games Have to Teach Us About Learning and Literacy*, Rev. and updated ed. New York: Palgrave Macmillan, 2007.
- [5] R. Koster, *A Theory of Fun for Game Design*. Scottsdale, AZ: Paraglyph Press, 2005.
- [6] D. Michael, *Serious Games: Games That Educate, Train and Inform*. Boston, Mass.: Thomson Course Technology, 2006.
- [7] M. Prensky, *Digital Game-Based Learning*. New York: McGraw-Hill, 2001.
- [8] M. Prensky, *"Don't bother me Mom, I'm learning!" : How Computer and Video Games are Preparing Your Kids for Twenty-First Century Success and How You Can Help!*, 1st ed. St. Paul, Minn.: Paragon House, 2006.
- [9] B. E. Shelton and D. A. Wiley, Eds., *The Design and Use of Simulation Computer Games in Education* (Modeling and Simulations for Learning and Instruction. Rotterdam, The Netherlands: Sense Publishers, 2007.
- [10] R. Garris, R. Ahlers, and J. E. Driskell, "Games, Motivation, and Learning: A Research and Practice Model," *Simulation & Gaming*, vol. 33, pp. 441-467, December 1, 2002.
- [11] K. A. Wilson, W. L. Bedwell, E. H. Lazzara, E. Salas, C. S. Burke, J. L. Estock, K. L. Orvis, and C. Conkey, "Relationships Between Game Attributes and Learning Outcomes," *Simulation & Gaming*, vol. 40, pp. 217-266, April 1, 2009.
- [12] D. Crookall, "Serious Games, Debriefing, and Simulation/Gaming as a Discipline," *Simulation & Gaming*, vol. 41, pp. 898-920, December 1, 2010.
- [13] D. Myers, "Guest Editorial: Video games: Issues in Research and Learning," *Simulation & Gaming*, vol. 36, pp. 442-446, December 1, 2005.
- [14] D. Williams, "Bridging the Methodological Divide in Game Research," *Simulation & Gaming*, vol. 36, pp. 447-463, December 1, 2005.

- [15] S. L. Kent, *The Ultimate History of Video Games*, 1st ed. Roseville, Calif.: Prima Pub., 2001.
- [16] C. Crawford, *On Game Design*. Boston: New Riders Publishing, 2003.
- [17] C. Crawford, *The Art of Computer Game Design*. Berkeley, Calif.: Osborne/McGraw-Hill, 1982.
- [18] J. Schell, "Design Outside the Box," in *Design Innovate Communicate Entertain*, Las Vegas, NV, 2010.
- [19] J. Schell, *The Art of Game Design : A Book of Lenses*. Amsterdam ; Boston: Elsevier/Morgan Kaufmann, 2008.
- [20] K. Salen and E. Zimmerman, *Rules of Play: Game Design Fundamentals*. Cambridge: MIT Press, 2003.
- [21] B. Brathwaithe and I. Schrieber, *Challenges for Game Designers: Non-Digital Exercises for Video Game Designers*. Boston, MA: Charles River Media, 2009.
- [22] Merriam-Webster Inc. (2010). *Game - Definition and More from the Free Merriam-Webster Dictionary*. Available: <http://www.merriam-webster.com/dictionary/game>
- [23] R. Caillois, *Man, Play and Games*. New York: Free Press of Glencow, 1961.
- [24] C. C. Abt, *Serious Games*. New York,: Viking Press, 1970.
- [25] J. Juul, *Half-real : video games between real rules and fictional worlds*. Cambridge, Mass.: MIT Press, 2005.
- [26] S. Miyamoto, T. Tezuka, and H. Yamauchi, "Super Mario Bros.," ed: Nintendo Co., Ltd., 1985.
- [27] Michigan State University. (2010). *MSU Serious Games Design Program*. Available: <http://seriousgames.msu.edu/>
- [28] O. S. Card, *Ender's Game*. New York, N.Y.: T. Doherty Associates, 1985.
- [29] N. Stephenson, *The Diamond Age, or, Young Lady's Illustrated Primer*. New York: Bantam Books, 1995.
- [30] C. J. Ferguson, C. San Miguel, A. Garza, and J. M. Jerabeck, "A Longitudinal Test of Video Game Violence Influences on Dating and Aggression: A 3-year Longitudinal Study of Adolescents," *Journal of Psychiatric Research*, vol. 46, pp. 141-146, 2012.
- [31] K. L. Becker-Olsen and P. A. Norberg, "Caution, Animated Violence," *Journal of Advertising*, vol. 39, pp. 83-94, Winter 2010.

- [32] C. McLeroy. (2008, September) The History of Military Gaming. *Soldiers*. 3.
- [33] funbrain.com. (2010). *Grammar Gorillas*. Available: <http://www.funbrain.com/grammar/index.html>
- [34] KidsNumbers.com. (2010). *Snork's Long Division Game*. Available: <http://www.kidsnumbers.com/long-division.php>
- [35] D. Shaffer, "In Praise of Epistemology," in *The Design and Use of Simulation Computer Games in Education*, B. Shelton and D. A. Wiley, Eds., ed Rotterdam: Sense Publishers, 2007, pp. 7 - 27.
- [36] C. Camargo. (2006). Interesting Complexity: Sid Meier and the Secrets of Game Design. *Crossroads: The ACM Student Magazine*. Available: <http://www.acm.org/crossroads/xrds13-2/sidmeier.html>
- [37] T. Lenoir and H. Lowood. (2003). Theaters of War: The Military-Entertainment Complex. Available: http://www.stanford.edu/dept/HPST/TimLenoir/Publications/Lenoir-Lowood_TheatersOfWar.pdf
- [38] Electronic Arts. (2012). *Battlefield Games - EA*. Available: <http://www.ea.com/battlefield>
- [39] Activision-Blizzard. (2011). *Call of Duty*. Available: <http://www.callofduty.com/>
- [40] Bohemia Interactive Simulations. (2010). *BISimulations*. Available: <http://www.bisimulations.com/>
- [41] Linde Research, Inc., (2012). *Virtual Worlds, Avatars, free 3D chat, online meetings - Second Life Official Site*. Available: <http://secondlife.com/>
- [42] Blizzard Entertainment Inc. (2010). *World of Warcraft Community Site*. Available: <http://www.worldofwarcraft.com/index.xml>
- [43] N. Ducheneaut, N. Yee, E. Nickell, and R. J. Moore, "Building an MMO With Mass Appeal," *Games and Culture*, vol. 1, pp. 281-317, October 1, 2006.
- [44] K. Graft. (2010). *EA: Budgets for Games Going In Reverse Direction*. Available: http://www.gamasutra.com/view/news/30075/EA_Budgets_For_Games_Going_In_Reverse_Direction.php
- [45] Y. Takatsuki. (2007). *Cost headache for game developers*. Available: <http://news.bbc.co.uk/2/hi/business/7151961.stm>
- [46] J. Juul, *A Casual Revolution: Reinventing Video Games and Their Players*. Cambridge, MA: MIT Press, 2010.

- [47] L. Papworth. (2009). *The Role of Leaderboards in Online Communities*. Available: <http://laurelpapworth.com/the-role-of-leaderboards-in-online-communities/>
- [48] Los Alamos National Laboratory, LLC,. (2011). *Periodic Table of elements: Los Alamos National Laboratory*.
- [49] Virginia Department of Education. (2011). *VDOE :: Science Standards of Learning*. Available: http://www.doe.virginia.gov/testing/sol/standards_docs/science/index.shtml
- [50] College of Sciences. (2011). *Old Dominion University Department of Chemistry and Biochemistry Undergraduate Course Descriptions*. Available: http://sci.odu.edu/chemistry/academics/under_courses.shtml
- [51] J. L. Devore, *Probability and Statistics for Engineering and the Sciences*, 6th ed. Belmont, CA: Thomson-Brooks/Cole, 2004.
- [52] D. C. Montgomery and G. C. Runger, *Applied Statistics and Probability for Engineers*, 3rd ed. New York: Wiley, 2003.
- [53] D. J. Rumsey, *Statistics for Dummies*. Hoboken, N.J.: Wiley, 2003.
- [54] D. J. Rumsey, *Statistics II for Dummies*. Hoboken, NJ ;: Wiley Pub., 2009.
- [55] B. L. Welch, "The Generalization of 'Student's' Problem when Several Different Population Variances are Involved," *Biometrika*, vol. 34, pp. 28-35, January 1, 1947 1947.
- [56] N. L. Johnson, S. Kotz, and N. Balakrishnan, *Continuous Univariate Distributions*. New York: Wiley, 1994.
- [57] R. Lowry. (2012). *Statistical Tables Calculator* Available: <http://vassarstats.net/tabs.html>
- [58] R. E. Nisbett and T. D. Wilson, "The Halo Effect: Evidence for Unconscious Alteration of Judgments," *Journal of Personality and Social Psychology*, vol. 35, pp. 250-256, 1977.
- [59] Develop. (2009). *Interview: Krome's Robert Walsh*. Available: <http://www.develop-online.net/features/484/Interview-Kromes-Robert-Walsh>
- [60] D. Schubert, "Designing Choice," *Game Developer Magazine*, p. 2, 2008.
- [61] P. Williams and S. Sheridan, "Conditions for Collaborative Learning and Constructive Competition in School," *Educational Research*, vol. 52, pp. 335-350, 2010.

- [62] S. Sheridan and P. Williams, "Developing Individual Goals, Shared Goals, and the Goals of Others: Dimensions of Constructive Competition in Learning Contexts," *Scandinavian Journal of Educational Research*, vol. 55, pp. 145-164, 2011.
- [63] J. C. Burguillo, "Using Game Theory and Competition-Based Learning to Stimulate Student Motivation and Performance," *Computers & Education*, vol. 55, pp. 566-575, 2010.
- [64] Entertainment Software Association, "2010 Sales, Demographic and Usage Data," The Entertainment Software Association, 2010.
- [65] UMB TechWeb. (2011). *Gamasutra - The Art & Business of Making Games*. Available: <http://gamasutra.com/>
- [66] C. Totten, "Mechanics vs. Motif," in *Christopher Totten's Blog* vol. 2010, ed: UMB TechWeb, 2010.
- [67] R. Hunicke, M. Leblanc, and R. Zubek, "MDA: A Formal Approach to Game Design and Game Research," presented at the Challenges in Games AI Workshop, Nineteenth National Conference of Artificial Intelligence, San Jose, California, USA, 2004.
- [68] D. Ramey. (2010). *Coolmath's Lemonade Stand Game*. Available: <http://www.coolmath-games.com/lemonade/>
- [69] M. P. J. Habgood, "The Effective Integration of Digital Games and Learning Content," Philosophy, University of Nottingham, 2007.
- [70] M. P. J. Habgood, S. E. Ainsworth, and S. Benford, "Endogenous Fantasy and Learning in Digital Games," *Simulation & Gaming*, vol. 36, pp. 483-498, 2005.
- [71] G. R. Morrison, S. M. Ross, and J. E. Kemp, *Designing effective instruction*, 5th ed. Hoboken, NJ: J. Wiley, 2007.
- [72] L. W. Anderson, D. R. Krathwohl, and B. S. Bloom, *A taxonomy for Learning, Teaching, and Assessing : a Revision of Bloom's Taxonomy of Educational Objectives*, Complete ed. New York: Longman, 2001.
- [73] L. W. Anderson and L. A. Sosniak, *Bloom's Taxonomy : A Forty-Year Retrospective*. Chicago: NSSE : Distributed by the University of Chicago Press, 1994.
- [74] S. I. Park, G. Lee, and M. Kim, "Do Students Benefit Equally from Interactive Computer Simulations Regardless of Prior Knowledge Levels?," *Computers & Education*, vol. 52, pp. 649-655, 2009.

- [75] S. Alessi, "Fidelity in the Design of Instructional Simulations," *Journal of Computer-Based Instruction*, vol. 15, pp. 40-47, 1988.
- [76] J. Sweller, "Cognitive Load Theory, Learning Difficulty, and Instructional Design," *Learning & Instruction*, vol. 4, pp. 295-312, 1994.
- [77] H. Lee, J. L. Plass, and B. D. Homer, "Optimizing Cognitive Load for Learning From Computer-Based Science Simulations," *Journal of Educational Psychology*, vol. 98, p. 902, 2006.
- [78] G. R. Morrison, *Designing effective instruction*, 6th ed. Hoboken, NJ: Wiley, 2011.
- [79] EA Canada, "FIFA Soccer 12," ed. Redwood, CA: EA Sports, 2011.
- [80] Visual Concepts, "NBA 2K12," ed. Novato, CA: 2K Sports, 2011.
- [81] EA Tiburon, "Madden NFL 12," ed. Redwood, CA: EA Sports, 2011.
- [82] Platinum Games, "Bayonetta," ed. Tokyo: Sega Corporation, 2010.
- [83] Tecmo, "Ninja Gaiden," T. Itagaki, Ed., ed. Tokyo: Tecmo, 2004.
- [84] Harmonix Studios, "Guitar Hero," ed. Cambridge, MA: RedOctane, 2005.
- [85] Harmonix Studios, "Dance Central," ed. New York City: MTV Games, 2010.
- [86] Nintendo Entertainment Analysis and Development, "Wii Fit," ed. Kyoto: Nintendo Co., Ltd., 2007.
- [87] Bungie, Inc., "Halo: Reach," ed. Redmond, WA: Microsoft Studios, 2010.
- [88] Infinity Ward, "Call of Duty 4: Modern Warfare," ed. Santa Monica, CA: Activision, 2007.
- [89] Danger Close, EA Los Angeles, "Medal of Honor," ed. Redwood City, CA: Electronic Arts, Inc., 2010.
- [90] EA Black Box, "Need For Speed: World," ed. Redwood City, CA: Electronic Arts, Inc., 2010.
- [91] Turn 10 Studios, "Forza Motorsport," ed. Redmond, WA: Microsoft Game Studios, 2005.
- [92] Rockstar North, "Grand Theft Auto IV," ed. New York City: Rockstar Games, 2008.
- [93] Naughty Dog, Inc., "Uncharted: Drake's Fortune," ed. Tokyo: Sony Computer Entertainment, 2007.

- [94] Blizzard Entertainment Inc, "Starcraft," ed. Irvine, CA: Blizzard Entertainment Inc, 1998.
- [95] Firaxis Games, "Sid Meier's Civilization V," ed. New York City: 2K Games, 2010.
- [96] Square Co., Ltd., "Final Fantasy," ed. Tokyo: Square, Co, Ltd., 1987.
- [97] Bioware, "Mass Effect 2," ed. Redwood City, CA: Electronic Art, Inc., 2010.
- [98] YUKE's Future Media Creators, "WWE SmackDown vs. Raw 2011," ed. Agoura Hills, CA: THQ Inc., 2010.
- [99] Capcom Co., Ltd., "Street Fighter," ed. Osaka: Capcom Co., Ltd., 1987.
- [100] United States Army, "America's Army," ed. Monterey, CA: Unites States Army, 2002.
- [101] Virginia Department of Education. (2011). *VDOE :: The Standards & SOL-Based Instructional Resources*. Available:
http://www.doe.virginia.gov/testing/sol/standards_docs/index.shtml
- [102] Ludoscience. (2012). *Serious Game Classification*. Available:
<http://serious.gameclassification.com/EN/index.html>
- [103] Minnesota Educational Computing Consortium, "Oregon Trail," ed. Eugene, OR: Brøderbund Software, Inc., 1971.
- [104] Valve Corporation, "Portal," ed. Bellevue, WA: Valve Corporation, 2007.
- [105] M. Persson, "Minecraft," ed. Stockholm, Sweden: Mojang AB, 2011.
- [106] F. Dille, *The Ultimate Guide to Video Game Writing and Design*. New York: Watson-Guptill Publications, 2007.
- [107] A. Rollings and E. Adams, *Andrew Rollings and Ernest Adams On Game Design*, 1st ed. Indianapolis, Ind.: New Riders, 2003.
- [108] R. M. Gagné, L. J. Briggs, and W. W. Wager, *Principles of Instructional Design*. Fort Worth: Harcourt Brace Jovanovich College Publishers, 1992.
- [109] J. M. Keller, "Development and Use of the ARCS Model of Motivational Design," *Journal of Instructional Development*, vol. 10, pp. 2-10, 1987.
- [110] A. Amory, "Game Object Model Version II: A Theoretical Frameworkfor Educational Game Development," *Education Tech Research Dev*, vol. 55, p. 27, 2007.
- [111] Westwood Studios, "Command & Conquer," ed: Electronic Arts, 1998.

- [112] J. Fleming. (2007). The History of Activision. *Gamasutra*. Available: http://www.gamasutra.com/view/feature/1537/the_history_of_activision.php
- [113] G. Bowditch, "Grand Theft Auto Producer is Godfather of Gaming," in *The Sunday Times*, ed. London: Times Newspaper Ltd, 2008.
- [114] S. Parkin. (2009). The Edge of Reason? *Eurogamer*. Available: <http://www.eurogamer.net/articles/the-edge-of-reason>
- [115] S. Dredge. (2011). Angry Birds: 200m Downloads are the Tip of the Mobile Gamine Iceberg. *guardian.co.uk*. Available: <http://www.guardian.co.uk/technology/appsblog/2011/may/19/iphone-game-stats>
- [116] H. Fuld. (2010). Peter Vesterbacka, Maker of Angry Birds Talks about the Birds, Apple, Android, Nokia, and Palm/HP. *Tech n' Marketing*. Available: <http://technmarketing.com/iphone/peter-vesterbacka-maker-of-angry-birds-talks-about-the-birds-apple-android-nokia-and-palmhp/>
- [117] B. Sinclair. (2009). America's Army bill: \$32.8 million. *Gamespot*. Available: <http://www.gamespot.com/news/6242635/americas-army-bill-328-million>
- [118] 2D Boy, "World of Goo," ed. San Francisco, CA: 2D Boy, 2008.
- [119] University of Washington, "Foldit," ed. Seattle, WA: Univeristy of Washington, 2008.
- [120] MST Inc., "School House: 30 Educational Programs," ed: MST Inc., 1991.
- [121] North Carolina State University, "Terraform," ed. Raleigh, NC: North Carolina State University, 2010.
- [122] Center for Game Science at University of Washington, "Foldit," ed. Seattle, WA, 2008.
- [123] E. A. Moore. (2011). *Foldit game leads to AIDS research breakthrough*. Available: http://news.cnet.com/8301-27083_3-20108365-247/foldit-game-leads-to-aids-research-breakthrough/
- [124] Ohio Distinctive Software, "ChemRacer 2713: The Legend of Kid Chem," ed. Columbus, OH: Ohio Distinctive Software, 1999.
- [125] J. France, J. Frucht, R. Gerleve, R. Harwell, M. Klawiter, A. Macik, and T. Silloway, "Compound Reaction," ed. Raleigh, NC: North Carolina State University, 2008.
- [126] HEUREKA-Klett Softwareverlag GmbH, "Chemicus: Journey to the Other Side," ed: HEUREKA-Klett Softwareverlag GmbH, 2001.

- [127] Abylight, "Afterzoom," ed. Kyoto: Nintendo Co., Ltd., 2011. Available: <http://www.abylight.com/afterzoom>
- [128] D. Nikdel, "MeChem," ed, 2004.
- [129] P. A. Fishwick, "Aesthetic Programming: Crafting Personalized Software," *Leonardo*, vol. 35, pp. 383-389, 2002.
- [130] P. Fishwick, S. Diehl, J. Prophet, and J. Löwgren, "Perspectives on Aesthetic Computing," *Leonardo*, vol. 38, pp. 133-141, 2005.
- [131] P. Fishwick, "Enhancing Experiential and Subjective Qualities of Discrete Structure Representations with Aesthetic Computing," *Journal of Visual Languages & Computing*, vol. 16, pp. 406-427, 2005.

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