THE DEVELOPMENT OF A HUMAN-CENTRIC FUZZY MATHEMATICAL MEASURE OF HUMAN ENGAGEMENT IN INTERACTIVE MULTIMEDIA SYSTEMS AND APPLICATIONS

by

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ABSTRACT

The utilization of fuzzy mathematical modeling for the quantification of the Human Engagement is an innovative approach within Interactive Multimedia applications (mainly video-based games designed to entertain or train participants on intended topics of interest) that can result in measurable and repeatable results. These results can then be used to generate a cogent Human Engagement definition. This research is designed to apply proven quantification techniques and Industrial/Systems Engineering methodologies to nontraditional environments such as Interactive Multimedia. The outcomes of this research will provide the foundation, initial steps and preliminary validation for the development of a systematic fuzzy theoretical model to be applied for the quantification of Human Engagement.

Why is there a need for Interactive Multimedia applications in commercial and educational environments including K-20 educational systems and industry? In the latter case, the debate over education reform has drawn from referenced areas within the Industrial Engineering community including quality, continuous improvement, benchmarking and metrics development, data analysis, and scientific/systemic justification requirements. In spite of these applications, the literature does not reflect a consistent and broad application of these techniques in addressing the evaluation and quantification of Human Engagement in Interactive Multimedia. It is strongly believed that until an administrative based Human Engagement definition is created and accepted, the benefits of Interactive Multimedia may not be fully realized. The influence of gaming on society is quite apparent. For example, the increased governmental appropriations for

Simulations & Modeling development as well as the estimated multi-billion dollar consumer PC/console game market are evidence of Interactive Multimedia opportunity.

This body of work will identify factors that address the actual and perceived levels of Human Engagement in Interactive Multimedia systems and Virtual Environments and factor degrees of existence necessary to quantify and measure Human Engagement. Finally, the research will quantify the inputs and produce a model that provides a numeric value that defines the level of Human Engagement as it is evaluated within the interactive multimedia application area. This Human Engagement definition can then be used as the basis of study within other application areas of interest.

This work is dedicated to all of those in the quest to obtain knowledge and progress humankind, at the price of sacrificed self-ambition.

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LIST OF ACRONYMS/ABBREVIATIONS

AHP	Analytic Hierarchy Process
ANS	Autonomic Nervous System
BIP	Breaks in Presence
DOT	Degree of Trueness
DoD	US Department of Defense
EEG	Electroencephalography
GSR	Galvanic Skin Response (or Electrodermal Response EDR)
HCI	Human Computer Interface
HPCDI	Human Perception and Cognitive Demands
FST	Fuzzy Set Theory
MPA	Magazine Publishers of America
NES	Nintendo Entertainment System
SNS	Sympathetic Nervous System
SME	Subject Matter Expert

CHAPTER ONE: INTRODUCTION

Application Areas of Human Engagement

The human experience can be defined as the detailed level of interaction between a human and the environment. The level of sensory stimulation and cognitive activity, comprise the gross Human Engagement definition.

Human Engagement may be observed across various application areas including but not limited to:

1. Classroom Environments (Lectures and Study Sessions)
2. Entertainment (Movies, Shows, Presentations)
3. Text Media (Reading)
4. Commercial Marketing and Advertisement
5. Corporate Environments (Team Scenarios)
6. Internet Technology (User Interfaces)
7. Interactive Multimedia (Video/Computer Gaming)

This research will focus on the interactive multimedia application area based on the ubiquitous presence of video and computer gaming in society. Within this body of research interactive multimedia is defined as the collection of games, video games, computer games, simulations, and virtual environments, created with the intent to either entertain, educate, or train. Hence,

these different application types may be used interchangeably to represent the more general topic of interactive multimedia. There are times where specific references which delineate the differences in these generic labels, exists.

Video gaming and computer gaming terms have been used synonymously for the sake of simplicity, in actuality, though many core aspects are shared, there are noticeable differences. For starters, the platform or the way video game consoles are interfaced differs from computer gaming (which usually uses keyboard and mouse). Even the genres of the most frequently played games differ between the different modes of gaming. In essence, computer gaming tends to support simulations and virtual environments more readily than console based video gaming systems. Game types and genres outlined by the Entertainment Software Association (ESA) include:

1. Action
2. Adventure
3. Arcade
4. Children entertainment
5. Family entertainment
6. Fighting
7. Racing
8. Role-playing
9. Shooter
10. Simulators

11. Sport games (team)
12. Strategy

Though more specifically in this work, Role-Playing, Simulators, and Strategy games will be addressed. A subgenre which has recently come into existence, facilitated by Internet technology and expansive virtual worlds is called the MMORPG. The MMORPG fosters both the collaborative effort required in group activities as well as the environment to construct knowledge in a controlled problem-solving arena. Such activities are highly correlated with many current classroom environments. A researcher in the interactive multimedia creation field better describes the MMORPG as:

> "An MMORPG is a persistent, networked, interactive, narrative environment in which players collaborate, strategize, plan, and interact with objects, resources, and other players within a multimodal environment."

(Dickey, 2007)

The MMORPG has the potential to be a viable vehicle for educational technology implementation. It exhibits many characteristics of interest that mirror those of educational environments including:

1. Social Interactive Community
2. Quasi-open Environment (Allows Player Choice)
3. Requires Incremental Accomplishment

4. Behaviors/Task Scaffolding
5. Player-centered Environment
6. Immediate Player Feedback
7. Supports Constructivist/Inquiry based Instructional Methods

The human experience, how humans interact within a virtual interactive multimedia environment, will be studied and delineated.

Research Gaps in Interactive Multimedia Experiences

The breadth of this research spans multiple fields of study. Namely, there are eight areas, as seen in Figure 1, which were reviewed and will be further detailed in Chapter 2. However, the following list highlights gaps in the research with relation to each field's contribution:

1. There is a lack of a standard and systematic approach to interactive multimedia used to train and educate research (Kelly, GDC, 2006).
2. There is an apparent lack of convincing empirical data that delineates the effectiveness of interactive multimedia used for training (O'Neil, Wainess, & Baker, 2005).
3. Interactive multimedia based training is highly fragmented and disparate (Gee, GDC, 2006).
4. More motivation based research in interactive multimedia, used to train, should benefit researchers. Cognitive research dominates the human learning theory literature (O'Neil, Wainess, & Baker, 2005).

These research gaps are potential areas of opportunity in which this body of research is designed to address. Within the literature review, it was found that in addition to this body of work other nascent efforts have been established.

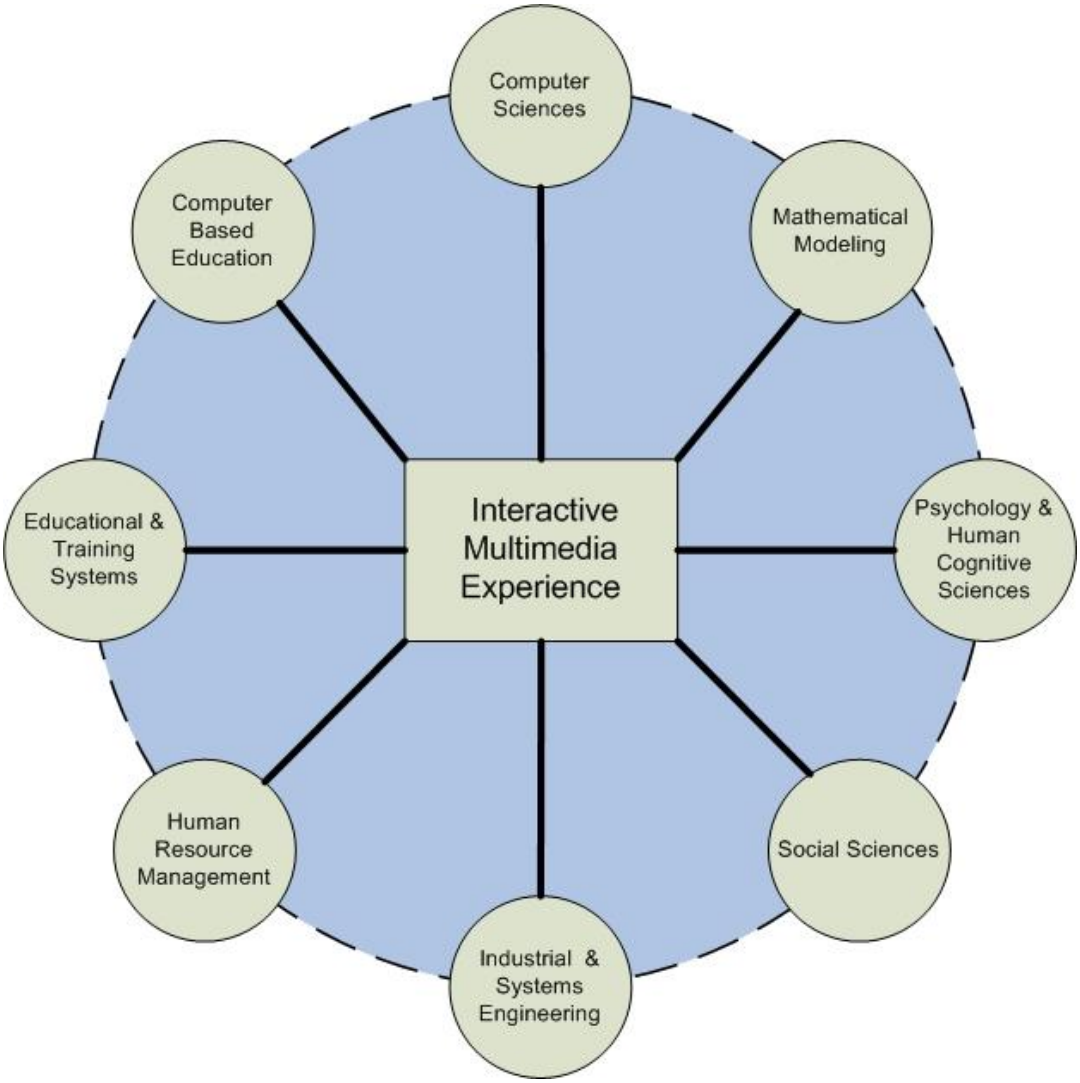


Figure 1 Interactive Multimedia Integration Model

Currently, there has been an increase in the number special interest groups (SIG's), created to address interactive multimedia used as a training tool, concerns. These efforts are the initial steps of a concerted approach to expand the human engagement estimation knowledge within the interactive multimedia application area.

Research Problem Statement

The usage of interactive multimedia education and training environments requires systematic and data driven quality initiatives (such as a Human Engagement heuristic), in order to facilitate full technology implementation. Other application environments that may benefit from a Human Engagement heuristic include: media, education, training, advertisement, and communication.

By creating a methodological framework to define standards and metrics should result in greater facilitation of implementation for interactive multimedia technology. So, why have we not experienced this mass implementation of interactive multimedia applications used to train, some three or more decades after the inception of the first commercial video game release? An answer believed by researchers is that the empirical data has not provided enough convincing evidence to systems' stakeholders and administrators who are responsible for mass adoption and implementation. The following quotes reiterate this very concern for lack of technology adoption:

> "Part of the problem, Gee said, is that the serious-games industry has yet to seriously define itself." Therefore, he said, those in the industry must concentrate on locking down what it is about. "We have to really confront the central questions and fight over them," Gee said, "so that there might be some central convergence."

(Gee, GDC, 2006)

"There's no tradition of research and systematic improvement in this industry," Kelly said. "Everything is a cottage industry."

(Kelly, GDC, 2006)

“Another problem”, Kelly argued, “is that serious-game developers have not arrived at any easily measurable standards for growth and success, and thus outside observers have a hard time judging whether projects work or not”.

(Kelly, GDC, 2006)

In other words, it is believed that in order to experience the benefits of interactive multimedia on a major scale, standards creation must occur, metrics must be created, and a convergence toward a central industry identity must exist.

Research Objectives

Research objectives of this body of work include:

1. Address the identified lack of a cross disciplinary metric and standard definition for Human Engagement, especially in the area of interactive multimedia & virtual environments.
2. Provide a framework and methodology that meets major systems stakeholders’ expectations by identifying and defining major factors that impact Human Engagement in interactive multimedia environments.

3. To develop a Human Engagement definition that is applicable to the interactive multimedia environment. The definition will address engagement from both a physiological and psychosocial perspective.

The move from a so-called "cottage industry" to a viable industry based on quality initiatives and systematic research should enable the desired growth just as evidenced in many other industries; such as automotive, electronics, education, consumer product manufacturing, and services. The method, which will be specified in detail in following Chapter 3 Methodology, will be utilized in this research, will be based on Fuzzy Mathematical modeling. This Fuzzy approach has exhibited much success in recent research by readily quantifying complex or qualitative data, such as Human Engagement, which in-turn can be used to assist stakeholders and administrators in making objective systems management decisions.

Successfully accomplishing the previous stated research objectives should result in a framework for developing a quantified Human Engagement definition and metric which adequately addresses various contributing fields of study's perspective, in this research, as it relates to the interactive multimedia application area. The proposed quantitative model will incorporate aspects of qualitative research (soft models), which tend to dominate the human cognitive improvement literature. This research is a step towards adding viable contributions to the body of research that has been identified by industry researchers such as James Paul Gee, Henry Kelly, Marc Prensky, and others. Pursuing research to define the Human Engagement factor was determined to have the greatest potential immediate impact within the literature since the usage

of the terms “engagement” and “engaged learning” within education and training, is quite extensive, see following table 1. A general survey of internet published literature, via internet searches on terms, concepts, and keywords common to interactive multimedia used to train, was conducted. The following table delineates information about the relative usage frequency of concepts that are commonly addressed in the literature. Next, research journal publications, presentations, articles, and other research specific offline publications were reviewed; in turn becoming the foundation of this research.

Table 1 Survey of Internet Published Interactive Multimedia Training Literature (Search Strings 11/2007)

Search String	Results (Hits)	Search Engine	Refers to
These words: “engaged” and “learning” Not these words: -wedding -marriage -ring -married -proposal -proposed -nuptials -civic -hitch	1,950,000	Google™	Human Engagement
These words: “engagement” and “learning” Not these words: -wedding -marriage -ring -married -proposal -proposed -nuptials -civic -hitch	535,000	Google™	Human Engagement
These words: “immersive” and “educational” and “game”	296,000	Google™	Application Design
These words: “presence” and “educational” and “game”	267,000	Google™	Application Design
These words: “realism” and “educational” and “game”	106,000	Google™	Application Design

Eventually this research may become the foundation for the creation of quantitative Human Engagement measures and standard, which traditionally, have been mostly qualitative in nature. Also, in efforts to define Human Engagement, the literature (O'Neil, Wainess, & Baker 2005) has stated that by augmenting Cognitive Learning Models, such as the University of Southern California/National Center for Research on Evaluation, Standards, and Student Testing (CRESST) model, with aspects of Motivation Theory, would expand the body of knowledge. Cognitive models are the foundation or start point in defining Human Engagement. Deimann and Keller (2006), Dickey (2005), Vogel (2006), Dipietro et al. (2007) and others, support the concept of motivation as a significant factor of human engagement in interactive multimedia training environments. Incorporating augmented motivation concepts in cognitive models can then be considered a secondary or lower-level research objective. The idea of Human Engagement appears within the literature usually discussed in the form of arousal. Indeed, O'Neil states that even interactive multimedia effectiveness may be documented as the intensity or longevity of engagement (O'Neil, Wainess, & Baker 2005). In order to determine game effectiveness, human engagement should be considered. Also, by developing and defining the human engagement factor, we would expect to enable system administrators to better assess the effectiveness of operations. Such an assessment tool would be beneficial to corporations, and especially public/governmental agencies, whose financial appropriations range in the hundreds of millions to billions of dollars annually. This lack of a robust and reliable means for evaluating and assessing implemented interactive multimedia technology has been reverberated within the literature; Dipietro, et al (2007), Dondi & Moretti (2007), and Kelly (2005).

Video/Computer Interactive Multimedia for Training

Prominent stakeholders across multiple disciplines including public and private sector administration, the sciences, education and economics, have concluded that the future of America relies heavily on the academic achievement and global diplomacy of its youth. Also, a skilled workforce is a key component to the American economy. The following quotes reiterate this notion that there is need for achievement and attainment of a skilled workforce:

"We are now reaching out to stakeholders, including researchers, corporations, government, the video games sector, to help us create a better future for all Americans—soon."

(FAS – Editor/Spokesperson)

"Learning enterprises need to adapt to the needs of young and old, citizens and recent immigrants."

(Kelly, FAS, 2006)

"Americans' lack of skills is holding back economic growth."

(Greenspan, 2006)

Major system stakeholders concur that without efforts to mitigate and reverse poor student achievement and an unskilled workforce, America should not expect to remain a global superpower; however there is hope that the full potential of interactive multimedia can be realized through concerted efforts which capitalize on popularity and appeal.

Video/Computer Game Usage Statistics

The following statistics are from the Entertainment Software Association (ESA) year 2006 Sales Demographic and Usage Data and related facts:

1. *67%* of American heads of households play computer or video games.
2. The average game player age is: 33
3. Game player ages by percentage: *28.2%* under 18 years, *47.6%* 18–49 years, *24.2%* 50+ years
4. *33%* of homes in America have a video game console.
5. Top 3 Selling Computer Games of 2006:
    a. World of Warcraft (MMORPG)
    b. The SIMS 2 (Simulation)
    c. The SIMS 2 Open For Business Expansion Pack (Simulation).
6. *55%* of parents believe games are a positive part of their children's lives.
7. *51%* of most frequent game players say they play games online, up from 19% in 2000.
8. Video and Computer game sales totaled $7.4 Billion in 2006
9. *41%* of Americans have purchased or plan to purchase one or more games in 2007.

Modern Serious Game & Training Applications

Perhaps there may be some apprehension about the utility of video and computer game/simulations that are actually useful in facilitating education and training. The traditional view is one that hypermedia including video and computer gaming has negatively impacted society, with the emphasis on the physical impact of obesity of the American youth as a result of their over-indulgence of video games or the claimed increase in violent behavior which supposedly mirrors game content. Yet, the positive impacts and potentials are boundless as nascent research activities have shown promise. Some contemporary applications of interactive multimedia and training span areas in medicine, military, economics, and education.

Medicine: Laparoscopic Surgery

The term Laparoscopic surgery, which is also referred to as minimally invasive surgery, describes the performance of surgical procedures with the assistance of video equipment and small telescoping instruments. During the surgical procedure, small incisions of up to half an inch are made and plastic tubes called ports are placed through these incisions. The camera and the instruments are then introduced through the ports which allow access to the inside of the patient. The benefits of Laparoscopic Surgery include:

1. Reduced blood loss, which equals less risk of needing a blood transfusion.
2. Smaller incision, which equals less pain and shorter recovery time.
3. Less pain, which equals less pain medication needed.

4. Reduced exposure of internal organs to possible external contaminants thereby reduced risk of acquiring infections.

According to Marc Prensky, a prominent contributor to the field of interactive multimedia (serious games & simulation), states that there are chief surgeons who recruit prospective surgeons, who exhibit characteristics, in addition to those acquired during medical schooling, which include evidence of significant video game play by these individuals. How would video game play support skill development in surgeons? Claims of increased visual acuity and hand-eye coordination were observed in recruits who were gamers versus their counterparts who did not play video games. Some Chief surgeons, who are supporters of surgeons who are avid gamers, require surgery preparation that includes video game play and warm-ups (Prensky, 2006).

Figure 2 Laparoscopic Surgery Simulation Setup

Military: Simulations and Training

The US military has used knowledge of interactive multimedia and simulations to train new recruits and veterans in the areas of:

1. Aircraft and Flight Operations
2. Tank and Armored Vehicle Operations
3. Theater and Field Operations
4. Emergency Response and Security

Thus, utilizing simulation in aircraft/flight operations seems quite logical, as to turn over a multimillion dollar aircraft to train a new recruit appears quite illogical. In many military related field or theater exercises, mission failure results in significant loss of life. Simulations allow training in a protected environment where failure is not terminal.

Figure 3 Microsoft's Flight Simulator for PC Screenshot

Economics: “Balancing the French Budget/ Cyber-budget”

The social impact of video and computer game simulations has even been applied to government administrative activities. For instance, the French government recently released an online simulation entitled “Cyber-budget” in May 2006. Players are given 3 assignments:

1. Preparing the Budget
2. Budget Programming Phase
3. Budget Management Phase

The gaming environment is modeled as closely as possible with the actual French government’s financial budget environment. Overall, in the end, France’s Budget Minister Jean-François Copé heads this initiative to educate France’s citizens on the country’s economic and financial vitality. The top 50 players of the game are to be given a tour of the Finance Ministry and will spend time with governmental officials.

Figure 4 French Finance Game "Cyber-budget" Screenshot

Education (K-12)

There is great potential in implementing interactive multimedia on a much wider scale in the K-12 educational system. Most notably is the preference for K-12 students to use computer-based technologies, video gaming, and electronic audio media versus traditional sources, to acquire information, to learn, and to relax. As presented earlier in this work, we can see that the statistics and demographic evidence to support the notion of an increased number of video game players, exists. Gaming design efforts in the areas of Reading, Social Studies, Language Arts, Science, and Mathematics currently exist.

Figure 5 Tabula Digita DimensionM Screenshot (Algebra Educational Game)

The IE Link to Human Engagement Measures

How is Industrial Engineering (IE) or the role of the Industrial Engineer defined within this body of work? The following quoted definition from IIE best describes this:

"Industrial Engineers figure out how to do things better. They engineer processes and systems that improve quality and productivity. They work to eliminate waste of time, money, materials, energy, and other commodities…. Industrial engineer is synonymous with systems integrator - a big-picture thinker, in other words"

(IIE, 2005)

Systems integration and cross-collaborative effort are believed to be what is required to ensure successful implementation and proliferation of interactive multimedia used for training in American society. The following topics/keywords are specific areas of focus, in which Industrial Engineering and Systems Engineers can assist system administrators of Serious Gaming applications and virtual environments attain their respective over-arching missions, topics include:

1. Quality Management
2. Metrics and Standards
3. Mathematical Modeling
4. Stakeholder Expectations
5. Systematic and Data Driven Decision-Making
6. Systems and Knowledge Integration

Engineering Management and Metrics Development

The importance of metrics and standards in an organization or industry, in this case, is often underestimated. They enable systems administrators and managers to more effectively and

efficiently create and execute operational protocols that result in increased positive results and successful implementation. These standards also allow for increased accountability and facilitate greater mission fulfillment. The following examples are existing metrics in traditional instructional environments and interactive multimedia environments.

Formative Methods

Formative methods of system effectiveness and assessment provide feedback and are usually continuous, from a program perspective. The following are types of formative assessment.

Traditional Engagement Metrics

1. Instruction/Curriculum Evaluation(s)
2. Time-on Task
3. Time-to Competency
4. Question Response Time
5. Number of Student Grievances
6. Number of Students requiring Remediation
7. Amount of time in Remedial Course
8. Number of Degrees Granted (Successful Completion)
9. Instructional Face-time
10. Attendance

11. Number of disciplinary Referrals Issued

12. Drop-out Rate (Unsuccessful Completion)

13. Number of Retained Students

14. Engagement Level

Human Engagement Metrics in Interactive Multimedia

1. Time-on Task
2. Time-to Level Completion
3. Task Response Time
4. Remedial Level Time Spent
5. Number of Failures to Success
6. Number of Breaks in Presence (BIPS)
7. Game/Server Uptime and Delays
8. Game Environment Processing Speed (Throughput)
9. Latency Lag Time
10. Level of Realism/Fidelity
11. Hardware metrics
12. Usability metrics, Human Computer Interface (HCI)
13. Number of Uncompleted Levels
14. Number of Completed Levels
15. Engagement Level

16. Game Usage Statistics

The above list includes metrics that impact Human Engagement in interactive multimedia systems. The hardware metrics category is an aggregate measure that includes many traditional computer science system measures. Intuitively, if there are issues with the system's hardware and software, Human Engagement will be significantly affected.

Summative Methods

Summative assessments are usually administered at the end of a unit or lesson and are a snapshot of academic mastery. The following are types of summative assessment:

Main Traditional Cognitive Task Metrics

1. Cognitive gains via assessment (Test Scores)
2. Task Mastery/Proficiency

Human Engagement Metrics in Interactive Multimedia

1. Game High Score (Normative)
2. Game Score
3. Task Mastery/Proficiency

In exploring the aforementioned metrics of traditional cognition, addressing the over-lapping metrics can be used as the foundation for evaluation of the interactive multimedia environment versus the traditional. Also, though some of the metrics may have different names they many times, essentially measure the same objectives. For instance, there may be high correlation between the following pairs of metrics from the traditional and interactive multimedia environment.

Table 2 Traditional vs. Interactive Multimedia Correlation

Traditional	**Interactive Multimedia**
Time-on Task	Time-on Task
Question Response Time	Task Response Time
Number of Degrees Granted (Successful Completion)	Number of Completed Levels
Number of Retained students	Number of Failures to Success
Instructional Face-time	Game/Server Uptime
Drop-out Rate (Unsuccessful Completion)	Number of Uncompleted Levels
Time-to Competency	Time-to Level Completion
Amount of time in Remedial Course	Remedial Level Time Spent
Instruction/Curriculum Evaluation(s)	Level of Realism/Fidelity
Instruction/Curriculum Evaluation(s)	Usability metrics, Human Computer Interface (HCI)
Instruction/Curriculum Evaluation(s)	Hardware metrics
Attendance	Game Usage Statistics
Engagement Level	Engagement Level

Metrics are critically important when assessing the quality of a system. The next section will introduce quality and how it will be addressed within this research.

The Quality Movement

What quality standards and continuous improvement philosophy did for the advancement of the automotive industry (early 1980's onward) can be a quite plausible expectation of the benefits that may be experienced within interactive multimedia technology. Main principles comprise the core quality philosophy.

Quality Principles and Standards – W. Edwards Deming, Joseph M. Juran, and Philip Crosby, arguably the most notable modern Quality gurus, approached the issue of Quality as a science and art. Quality will be defined as simply "Meeting or Exceeding Stakeholder Expectations" within this body of work. The primary stakeholders discussed within this research, system administrators, may be interested in assessing the levels of Human Engagement that enable them to manage and control system operations. It is pertinent that standards be created, implemented, and maintained in order to ensure system efficacy and efficiency. In the Serious Game industry, the need for quality has been recognized.

Recent attempts to formally organize the Serious Gaming Industry have resulted in conferences and events such as "The Serious Games Summit" which is an adjunct event of the larger Game Developers Conference. Yet, this step is only the first step in a seemingly daunting progression towards industry viability.

Chapter 1 Summary

1. The study interactive multimedia applications within this research, addresses the use of games, video games, computer games, and other virtual environments created with the intent to educate and train.
2. Gaps in the research include the lack of standard and systematic approaches to research within interactive multimedia. Also, human factors such as motivation are not adequately addressed within the literature when referencing Human Engagement. Overall, there must be more empirical data to show Human Engagement affects interactive multimedia effectiveness.
3. This body of work will address the need to provide a framework which can be utilized to create Human Engagement standards and metrics based on Fuzzy Mathematical modeling. Human Engagement measures appear to be significant when technology implementation is desired.
4. Scientists, government, and the private sector see the need for increasing productivity and efficiency.
5. Video game usage stats state that the average gamer is 33 years old. The majority of gamers are between the ages of 18 – 49 years. Roughly one third of American households own a gaming console. Overall video and computer game sales topped $7.4 billion in 2006.

6. Interactive multimedia has been applied to the medical, military, economic, and educational arena.
7. Industrial and Systems Engineers are integrators which can benefit the creation of Human Engagement definitions within the contemporary development of interactive multimedia technology.
8. Metrics Development is an important concept in which Formative and Summative methods of assessment can be utilized to indicate the status of a training system.
9. Quality standards and metrics are both key to the vitality of an organization or industry.

The next chapter will detail the Literature Search and the topics of interest as pertaining to this research.

CHAPTER TWO: LITERATURE REVIEW

Span of the Literature Review

The literature review in this research is interdisciplinary in nature and includes theory and research from the following fields of study. The following areas are start points which aid in defining Human Engagement within interactive multimedia:

1. Computer Sciences (Simulations and Virtual Environments)
2. Computer Based and e-Learning
3. Mathematical Modeling
4. Psychology and Human Cognitive Sciences
5. Social Sciences
6. Industrial and Systems Engineering
7. Human Resource Management
8. Educational and Training Systems

In addition to the aforementioned fields of study, there are many sub-fields which extend and become even more interdependent on diverse fields of study. See Appendix C for full Literature Review matrix.

Computer Sciences (Simulations and Virtual Environments)

Relevant topics in computer science that can contribute to a better understanding of interactive multimedia technology include:

1. Engagement Definition
2. Video and Computer Game Types
3. Commercial vs. Educational

Within these topic areas the literature references key personnel and institutions. A few of these referenced researchers are as follows:

1. Dr. Michelle Dickey
2. Dr. James Paul Gee
3. Dr. Henry Kelly
4. Marc Prensky
5. David Rejeski
6. Ben Sawyer
7. Clark Aldrich
8. Dr. Kay Stanney
9. Dr. Jan Cannon-Bowers

The following commentary addresses these topic areas in reference to interactive multimedia technology. The computer science research will focus on the actual gaming applications and how humans are impacted by their usage.

Commentary

- Engagement Definition

Game designers tend to define engagement as the focus of interactivity and feedback, the customization of gaming experience, the mitigation in consequences of failure (ex. game quick-save capabilities), ease of use, realism/presence, and narrative. These aspects of an individual's experience are related to a more summative approach of assessment to indicate the level Human Engagement or task completion. Surprisingly, when speaking of engagement, the literature does not show overwhelming empirical data to aid in drawing conclusions about the effectiveness of interactive multimedia vs. traditional teaching methods. Even Dr. J. P. Gee makes it clear that a well constructed game that utilizes a proven instructional design methodology will fare well versus a well constructed game that utilizes a poor instructional design framework. Simply, because instruction is in a game format does not guarantee greater academic achievement; though Gee absolutely acknowledges the potential of video games as influential interactive multimedia applications that impact a participants engagement level; also, Gee remarks about how commercial designers engage consumers differently than educational based interactive multimedia. Why are consumers motivated to pay for learning hard games? What would happen to the level of Human Engagement if a participant's perception of entitlement to completing cognitive tasks in educational games just as gamers feel entitled to playing commercial video

games? Customized user experiences are extremely important to levels of Human Engagement in respects to increasing participant entitlement. According to the literature, human perception and actions are deeply connected, i.e. human's are influenced to action based on perception. All in all, good games have concise and well ordered problems. When a customized and tailored experience is utilized this mimics how games allow participants to interact with an interactive multimedia environment at their own pace. Engagement extends beyond the virtual game environment design. The next section will address the design of interactive multimedia applications and how various factors may impact the level of Human Engagement.

- Video and Computer Game Types

Video games have become a fixture on the US cultural landscape. From their commercially viable inception in the early1970's until this very day, their impact, both good and bad, and their potential to educate and train, should not continue to be ignored. Ralph H. Baer, the proclaimed father of commercial video and electronic gaming, facilitated the evolution of games from novelties in research laboratories and on university campuses, to their ubiquitous presence in the American home. Taking the video gaming concept, with the original intent to entertain, and replacing this thought, with the intent to train, places emphasis on the possibilities of interactive multimedia training application. The oldest 1st generation gamers are now, on average, in their Mid-late 40's, and many have now established themselves in the corporate arena, hence the apparent surge in popularity of gaming. Once viewed as a past-time for children and adolescents, major commercial video game console producers have expanded their target markets to other demographic populations. Nintendo, Sony, and Microsoft have targeted young and middle-aged

adults (heads of households), who may have the disposable income to purchase their $300+ game systems. The following timeline, created by Amanda Kudler, indicates major milestones in the evolution of electronic video games and includes the economic viability of gaming:

1. **1958** Physicist Willy Higinbotham invents the first "video game" at the Brookhaven National Laboratory in Upton, New York. His game, a table tennis-like game, was played on an oscilloscope.
2. **1961** Steve Russell, a student at the Massachusetts Institute of Technology (MIT), creates Spacewar, the first interactive computer game. It runs on a Digital PDP-1 mainframe computer, and the graphics are made up of ASCII text characters.
3. **1966** Ralph Baer, an engineer at Sanders Associates, receives support from his company (a military electronics consulting firm in NH) to explore his idea of creating interactive games using a television.
4. **1967** Baer and team are successful in creating two interactive TV games—a chase game and a tennis game. They are also able to manipulate a toy gun so that it detects spots of light on the TV screen.
5. **1970** Magnavox licenses Baer's TV game from Sanders Associates Nolan Bushnell and Ted Dabney (future founders of Atari) begin their attempt to create an arcade version of Spacewar, calling it Computer Space.
6. **1971** Computer Space becomes first video arcade game ever released. 1500 games are distributed. Public consensus is that it is too difficult to play.

7. **1972** April 25 A U.S. patent is issued to Ralph Baer for "A Television Gaming Apparatus and Method" May 24 Magnavox's Odyssey, the first home video game system, is showcased at a convention in Burlingame, CA, and is released to the public later that year. Bushnell and Dabney found Atari. They name the company after a term from the Japanese game "Go". "Atari" is equivalent to "check" in a chess game.
8. **1975** Atari's Pong is released with help from Sears Roebuck, which finances the production of 150,000 units. It becomes the hottest selling Christmas present. Sears sells the product exclusively, with the Sears Tele-Games logo. Gunfight, the first "computer" game is released. It is the first game to use a microprocessor instead of hardwired solid-state circuits.
9. **1976** Coleco releases its first home video-game console called Telstar. Fairfield Camera & Instrument debuts its Video Entertainment System which is known later as Channel F. The first programmable (cartridge-based) home game console, it allowed users to change games by switching cartridges that resembled 8-track audio tapes.
10. **1977** Atari introduces its first cartridge-based home video system called the Video Computer System which later becomes known as the Atari 2600. It retails for $249.95.
11. **1978** The trackball makes its entrance into the video-game industry as the controller in Atari's new arcade game Football. Midway introduces Space Invaders into arcades. It is the first arcade game that tracks and displays high scores. Atari attempts to enter the computer industry to compete with Apple. The product is not taken seriously, and the Atari 400 and 800 are taken from the market.

12. **1979** Atari develops a handheld console that displays holograms. Named "Cosmos," this product was never released. Asteroids was the first game to allow high scorers to enter three character initials to be stored in the machine.
13. **1980** Mattel's Intelivision debuts and is the first real competitor of the Atari 2600. It has better graphics than Atari's 2600, but a higher retail price ($299). Activision becomes the first third-party video game vendor. The company is created by Atari programmers who want to receive individual credit for creating Atari's video games. Battlezone is first 3-D game ever created. It is set in a virtual battlefield and was later enhanced by the U.S. government for training exercises. 300,000 units of Pac-Man are released worldwide by Namco. Defender, the first game incorporating a "virtual world" is introduced. The game uses a "radar" scope at the top of the screen to inform users of the surroundings since the screen is too small to display all of the action.
14. **1981** Arnie Katz and Bill Kunkel found the first video-game magazine, Electronic Games.
15. **1982** Atari releases the Atari 5200 to compete with Coleco's Colecovision.
16. **1983** Cinematronics debuts Rick Dyer's Dragon Lair, the first video game to feature laser-disc technology. The Commodore 64 is introduced. It is the most powerful video-game console to date and the least expensive. Nintendo introduces the Famicom in Japan—later known as the Nintendo Entertainment System (NES) in the U.S. Since Atari controls such a large percentage of the market, they do not plan to market the product in the U.S. Instead the company offers Atari the rights to distribute the product in the U.S. These plans fall through and Americans do not see Nintendo until 1985. Al Alcorn is

hired by Atari to program video games. The first game created by Atari is Pong. Ping-Pong, the original name, is already copyrighted, so the makers name it Pong after the sound of a ball hitting the paddle.

17. **1985** The popular game Tetris is developed by Russian programmer Alex Pajitnov. It is played on a PC.
18. **1986** Nintendo's NES is released in the U.S. after being test-marketed in NY one year earlier. To compete with the NES, Sega introduces the Sega Master System (SMS). Atari releases the Atari 7800 to stay competitive in the market.
19. **1989** Nintendo releases the handheld Game Boy for $109. NEC releases the first 16-bit console in the U.S. It is called the TurboGrafx-16 and sold for $189. It is the first system to run video games stored on compact discs. The true arcade experience comes into American homes when Sega debuts the Genesis, its first 16-bit home game console, for $249.95. Atari tries to enter the handheld market with the Lynx, a color handheld console retailing for $149.
20. **1991** Super NES is released in the U.S. by Nintendo for $249.95.
21. **1993** Atari releases the Jaguar, attempting to be the first 64-bit console on the market. The product actually runs two 32-bit processors. Senators Joseph Lieberman of Connecticut and Herbert Kohl of Wisconsin launch a Senate investigation into violence in video games, hoping to initiate a ban on violent games.
22. **1994** Resulting from the Senate investigation, the Entertainment Software Rating Board is created. Ratings are now given to video games and are marked on the games'

packaging to indicate the suggested age of players and violent content. In Japan, the Sega Saturn and the Sony PlayStation make their debut.

23. **1995** Sony brings the PlayStation to the U.S. and sells the console for $299. Nintendo releases the Nintendo 64 in Japan (it's released in the U.S. in 1996).
24. **1996** Arcades focus on bringing in more "ride-and-video" games like skiing, snowboarding, and Jet Skiing, as their popularity has surpassed the popularity of shooting and fighting games. Atari's founder, Nolan Bushnell, reenters the industry making Internet stations for arcades and bars. The Tamagotchi virtual pet becomes an instant sensation in Japan. It is released in the U.S. in May of that year selling all of its 30,000-unit supply in 3 days.
25. **1997** PlayStation is considered by many in the industry as most popular game console as the 20 millionth unit is sold. Tiger introduces a multipurpose handheld console to compete with the Game Boy. Called game.com, it features games, an address book, calculator, and stylus for touch-screen capability. It also connects to a PC modem for access to email,
26. **1998** Sega introduces the Dreamcast in Japan. This console operates on Microsoft Windows CE which will allow for easier conversions between Dreamcast and PC games. The Wal-Mart retail chain decides to ban over 50 video games that it deems inappropriate for minors.
27. **1999** Billy Mitchell attains a score of 3,333,360 in the game Pac-Man. This is the highest possible score a player can get. As a result of the shootings that occurred at Columbine High School in Littleton, Colorado, Sega announces that it will not release a light gun

with the Dreamcast in the U.S. In addition, it prevents use of imported guns with American consoles, which forces the Americans to use standard controllers to play the popular House of the Dead 2.

28. **2000** Sony's PlayStation 2 launches in the U.S. for $299.99 and is sold out by early morning. Since the demand is so high and only 500,000 units are available, it is very difficult to buy a unit during this first shipment. The Sims® is released, and quickly becomes a hit. It eventually (in 2002) surpasses Myst® as the best-selling PC game ever.
29. **2001** Microsoft and Nintendo introduce their next-generation systems within days of each other. Microsoft claims its Xbox offers "the most powerful game experiences ever." The product (estimated retail price of $299.99) comes with a built-in hard drive and Ethernet port. Nintendo's GameCube (suggested retail price of $199.95) delivers new forms of interactive gaming for players and an easier development environment for game creators. Sega announces that it will no longer manufacture hardware. Nintendo releases the GameBoy Advance ®, a portable gaming system.
30. **2004** Nintendo releases the Nintendo DS, a portable system with two screens, one of which can be used as a touch screen.
31. **2005** Sony releases the PSP, a portable system with a large, high-resolution display. Microsoft unveils the Xbox 360®, a console system to be released in November 2005. Sony and Nintendo's competing console systems are planned for release in 2006.

The evolution of the video/computer game spans nearly five decades, yet a commercially viable game system was not introduced until sometime after the first original game was created. Here’s

an interesting point to note, the US government (DoD), mulled The popularity of using video and computer games to educate has prompted much research. There are many different types of video games that can be utilized to entertain, educate, and train. Some of the types of games include:

1. Action
2. Adventure
3. Arcade
4. Children entertainment
5. Family entertainment
6. Fighting
7. Racing
8. Role-playing (MMORPG – Casual and Serious)
9. Shooter
10. Simulators
11. Sport games (team)
12. Strategy

According to research there appears to be a substantial interest in utilizing MMORPG's as major interactive multimedia applications used to train. Gee, Dickey, Prensky, and others have written publications that support the current research to utilize MMORPG's. The structure of the MMORPG varies from other games in terms of actual game-play. For instance, multiple narrative storylines exist simultaneously and do not end when the player logs off; though a single

loosely defined high-level goal exists (Dickey, 2007). Traditional training environments are multimodal just as MMORPG's. Hence, the MMORPG type of gaming application appears well suited for training. The game-play of the MMORPG is very similar to other games mainly in aesthetics and feel (ex. 3-D Environments, 1st & 3rd person character perspectives, and animated game agents). The difference is that many entities in the virtual MMORPG environment are connected to the real world. Characters are actually avatars, or symbolic representations of real people, and the environment or virtual universe is accessible to participants from anywhere on earth that has internet access. Hence, the social aspect of the MMORPG has great potential in providing a more immersive experience for participants. Game-play actions, known as Quests in the MMORPG environment, are specific types of missions or goals in which a player is directed to accomplish. The main types of Quests include:

1. Collection (Collect objects)
2. Goodwill (help another low-level player)
3. Fed Ex (Movement between environments where objects are to be delivered)
4. Messenger (Pass information to another player)
5. Bounty (Defeat a character for reward)
6. Escort (Escort Non-player character to another location) (Dickey 2007)

These aforementioned directed actions are in addition to basic navigation, transportation, and character interaction capabilities within the virtual environment. Current existing MMORPG's may be classified into sub-genres such as Fantasy, Shooters, Simulations, Real Life, Historical,

Horror, Super-heroes, Sports and Sci-fi. Names of current "Real Life" or simulated MMORPG's can be seen in the following table 3.

Table 3 "Real Life" MMORPG's

Game Name	Description	Screenshot
Habbo Hotel	Habbo is one the world's largest and fastest growing virtual worlds and social networking services for teenagers. Localized Habbo communities all around the world are visited by millions of teenagers every week.	
Oz World	Oz Online offers a breath of fresh air in today's combat-ruled MMORPG landscape. Instead of forcing players to compete against each other, this game promotes community and friendship by concentrating on friendly interactions and social gatherings.	
RAN Online	18 years ago on the sky above the land of Asia like never before an eclipse took place, in the dark, millions of falling stars flying across the sky.	
Second Life	Second Life is an expansive online society, lived in and built by its participants. Join a 3D world full of people, activity, and fun, where you and fellow residents can build a shared reality. You choose your own goals? Travel and explore, claim and build on virtual land, make friends and socialize, or vie for status and wealth. Whatever you choose to do, your Second Life starts now.	
The Agency	The Agency is a fast-paced, online persistent shooter in a modern setting of bullets, bomb blasts, and betrayal. Live the life of an elite agent in a world of super spies and rugged mercenaries, who use both the highest technology and the lowest tactics to accomplish their goals. Featuring cooperative and competitive play, The Agency is designed to provide instant action and long-term strategy for all fans of espionage, intrigue, and explosive game-play.	
The Sims Online	The Sims Online™ is the first online world from Will Wright, the creator of SimCity™ and The Sims™.	
There	There gives members the opportunity to connect with others while doing fun things together online, and express themselves in ways that are not possible with other forms of online socializing. Specifically	

Remember that the above table is only a list of classified Real Life MMORPG's and is somewhat limiting. For instance, the Fantasy category, another sub-genre, is by far the largest category. The Real Life sub-genre appears to appeal to trainers and administrators since virtual activity may be reinforced by real world experiences; the level of Human Engagement and experience may be impacted.

A featured Massive Multiplayer Online Game at the University of Central Florida's Institute of Simulation and Training called Lunar Quest, falls into the category of more serious games that have an educational intent (http://lunar-quest.com/overview.php). Lunar Quest uses real physics content and design engine to simulate a more realistic feel. This NSF funded project was originally created to assess the effectiveness of teaching entry-level physics via interactive multimedia.

So, what is the difference in commercial gaming and educational gaming? The next section will address this question.

- Commercial vs. Educational

According to literature data, entertainment based games sell more units than educational based games (ESA, 2007). Why? Gee seemingly asks similar questions in why work is seen as being tedious and hard while play is entertaining and enjoyable. Being an active participant is key to the success of commercial gaming. The literature states that interactivity in commercial games

differs from that of educational games. This is possibly due to the fact that educational games are not as player centered as commercial games. For instance, "Different styles of learning work better for different people. People cannot be agents of their own learning if they cannot make decisions about how their learning will work. At the same time, they should be able (and encouraged) to try new styles" (Gee, 2005). Limiting a participants experience can be enough to alienate them and negatively impact their level of engagement. The importance of incorporated game elements in simulations and educational gaming is often understated and underappreciated (Aldrich, 2004, 2005). Commercial interactive multimedia tends to incorporate game elements quite well. The consequences of failure are much greater in a reality; hence risk-taking and participant entitlement are mitigated, which in turn may negatively impact levels of Human Engagement. In essence, this traditional mindset and philosophy of instruction is transposed onto educational game design. On the other hand, good commercial games allow for greater player customization in game-play and a resultant increase in engagement. The commercial game's path promotes equifinality, multiple paths to a common single end. In contrast educational games are usually much more stringent in player customization since they are subject to underlying objectives; which when not aligned with participant interest can lead to bouts of de-motivation and disengagement. Another view of engagement from the commercial sector, magazine readership, further addresses the difference in the commercial versus the educational approach to obtaining knowledge via media.

Approaches by various commercial entities such as Magazine Publishers of America (MPA), include crafting a defined consumer engagement idea. Magazine Publishers of America's

approach to defining engagement includes various aspects which are of great interest to advertisers in addition to researchers in academia. For instance, the MPA states that defining engagement is difficult because it looks to quantify the qualitative. For instance, commercial advertisers (Magazine Publishers of America MPA, 2006) address the issue of engaging readers through ads by noting that emotional connection in terms of perceived enjoyment and likeability are important in understanding user/reader experience. Attentiveness, a major factor of engagement, correlates to elevated states of consumer arousal. This sense of engagement and attentiveness can be applied to the educational interactive multimedia experience. The emotional or socio-cultural connection of the commercial counters that of instructional design philosophy, which recommends that instruction be neutral, stripped away of potentially connotative and cultural inferences. Hence, differences in commercial versus educational gaming, design practices exist. The intent of the gaming experience will determine the form of the interactive multimedia application.

Different video game types, especially the MMORPG, are recognized for their ability to replicate the real world. Aspects of game design of MMORPG's tend to address issues of realism, fidelity, presence, game graphics and game physics. These factors have been identified as influencers of Human Engagement within the research literature.

Computer Based and e-Learning Interactive Multimedia

As an extension to the Computer Science literature review, this section will address relevant Computer-based interactive multimedia topics such as:

1. Educational Technology Movement
2. Online and Distributed Learning
3. Presence: Realism and Fidelity in Virtual Environment

Commentary

Computer-based interactive multimedia does not necessarily address computer gaming, though there may be references. The focus of this research will address the usage of computer technology and how the experience impacts Human Engagement. For the sake of simplicity, computers or any form of electronic computing used to educate or train will be considered computer based learning within this body of work.

- Educational Technology Movement

According to Wenglinsky, the Educational Technology Movement, which includes computer-based learning, was instituted in 1994 in America, with the support of three major stakeholders; US Federal Government, State Governments, and the Private Sector (Wenglinsky, 2005). The use technology in the classroom as supported by government became known as the Improving America's School Act of 1994, Section 2, Title II, Part A. It was believed that student academic

achievement could be improvement via a student's exposure to computer technology. As the focus of administrations shifted, there was legislation that focused on various aspects of computer technology implementation including:

1. Professional Development of Teachers: All teachers in the nation will have training and support they need to help students learn by using computers and the Internet.
2. Hardware Access: All teachers and students will have modern multimedia computers in their classrooms.
3. Connectivity: Every classroom will be connected to the Internet.
4. Digital Content: Effective software and online learning resources will be an integral part of every school's curriculum (Wenglinsky, 2005).

Appropriations in the form of the Technology Literacy Challenge Fund and the Technology Innovation Challenge Grants were important in legislation instituted in 1996. Additional legislation was passed, most notably, during the Clinton Administration from years 1994 – 2002.

From the literature review it was quite apparent that a systems integration approach proved valuable when attempting to address multiple stakeholder expectations during the implementation of educational technology. Hence, acquiring governmental and private sector buy-in is key to the full implementation of education technology.

- Online and Distance Learning

The age of the Internet introduced the average citizen to a world of information. The virtual world has some of the same and some distinct issues as the real world. A major concern may be funding online initiatives becomes the sole responsibility of systems administrators and government. Example, Florida, who is a pioneer in Virtual K-12 education, had reportedly spent $16 million to implement the Virtual High School program and additional funding in support (Wenglinsky, 2005). Other states such as South Dakota have been reported to have appropriated $35 million in equipment and software purchases alone.

From another perspective, one distinct benefit of distance learning is that it provides access to education which may have previously been inaccessible. Geographic and location related impediments were drastically mitigated as distance learning was implemented. Rural areas have access to education just as urban education institutions.

The reality of the virtual environment has become an important distinct issue as the popularity of online and distance learning increases. The next section will address the sense of presence, realism, and fidelity in a virtual environment. These factors also impact the level of Human Engagement.

- Presence: Realism and Fidelity in Virtual Environment

Realism and Fidelity have long been major measures of good game and computer based interactive multimedia design. Virtual world communications, physics, graphics/resolution, and

character design can impact a player's level of engagement according to research reviewed from the Game Developer's Conference (GDC) 2007. Top concerns of game designers were presented and addressed. Player engagement, in the form immersion, is an extremely important factor considered by game application designers. So, how has presence been defined in the past when describing interactive multimedia? Physiological response data has been used quite extensively to indicate presence, as will be discussed in the next section.

Studies using physiological response data, such as heart rate, in addition to qualitative questionnaires, have been conducted to determine presence. It is quite common that questionnaires, only, are used to determine the degree of presence a participant experiences. What is presence? Presence is a sense or feeling of being in a place. In essence, presence is a state of mind. Breaks in Presence (BIP) are events in which a participant in a virtual world responds more to real world sensory data and less to the virtual world (Slater, Brogni, & Steed, 2003). Breaks in presence are directly correlated to level of engagement. It is hypothesized that there is a physiological response that correlates to BIP that does not require qualitative data, yet the research does not exhibit compelling evidence as of this theory as of yet. The concept of presence is believed to be connected to human engagement in the interactive multimedia environment. In addition, graphic resolution, fidelity, and realism positively impacted cognitive gains according to Vogel et al. meta-analysis. This is an example of the potential benefit of applied simulations design, which replicates real environments. Across these studies there were also noticeable attitudinal changes amongst participants.

Research in simulations and video gaming is needed from Federal sources. Games are supplemental to teacher facilitation. The systems approach must be heeded to include developers, SME's, and researchers. Implemented research to keep players on the verge of anxiety, not too hard and not too easy as stated by researchers such as Gee, Yerkes, Dodson, and Zajonc to name a few, is something that should be considered with the intention to increase presence.

Mathematical Modeling

The following relevant topics were researched in order to attain a greater understanding of the Mathematical Modeling body of knowledge as pertaining to interactive multimedia which is the focus of this research:

1. Regression Analysis
2. Multicollinearity
3. Decision Analysis: Analytic Hierarchy Process (AHP)
4. Fuzzy Set Theory (FST)
5. Alternative Cognitive Models

Also, the key personnel and contributing institutions to the aforementioned study areas of this research are as follows:

1. Dr. Lotfi Zadeh
2. Dr. Thomas Saaty
3. Dr. Adedeji B. Badiru

4. Dr. Pamela McCauley-Bell
5. Dr. Hans J. Zimmerman

Notice that much of the mathematical modeling discussion will focus on the topic of FST coupled with Analytic Hierarchy Process.

Commentary

The field of Statistics provides the mathematical framework upon which research in simulations and virtual environments are based. Regression analysis, which utilizes statistics, is one of the most prevalent methods utilized to build mathematical models. The next sections will address the use of regression analysis and the valid reason(s) in knowing when and when not to appropriately use regression analysis.

- Regression Analysis

Regression Analysis is an extremely well known and widely accepted data analysis technique. One reason for its popularity is that regression analysis is an empirically derived, precision modeling method. Why is the term precision used? Precision refers to the ability of the modeling technique to produce repeatable and predictable measures, irregardless of the accuracy of target measures. Simply stated regression analysis is limited to and by the range of the data used to derive the regression model. Model usage for conditions which reside outside of the range of the data used to derive the regression model should be avoided since potential model error can not be

accounted for. Two common forms of regression analysis, discussed in the research, include the Multiple Regression Analysis method and the Simple Linear Regression Analysis method.

Multiple Regression analysis is an expansion of simple linear regression theory which includes multiple independent factors (x) in a common model that will impact or determine a dependent response (y). The following discussion will include the general forms for both Simple Linear Regression and Multiple Regression methodologies, since Multiple Regression analysis is predicated on the simple linear approach. There are some important things that should be considered when using Regression Analysis. In using regression analysis, the system to be modeled should be in statistical control (meaning Low Variability & Steady-State Operations) and that the resultant statistical distribution of the observed data should be identified (Myers & Montgomery 2002). Also, other foundational assumptions should be met such as:

1. Regression Model Error is Normally Distributed with a Mean Value = 0
2. Regression Model Error is Uncorrelated
3. Independence between factors should exist (i.e. correlation between factors should be minimal)

The reason to use Linear Regression is to create a model that represents an observed Real-World scenario. The process of creating a regression model begins with a single graphical line, referred to as the regression line, is fit to the observed data points, usually which have been displayed using a scatter diagram. The most common method used for determining this single line that has the minimum summed error or deviation between the line and data points is referred to as the

Least Squares Method. The Least Squares Method examines a series of data points in relation to the suggested regression line that results in the least squared amount of deviation between each point and the line, which is then converted to Sum Squared Error (SSE) by squaring the deviations to prevent negative signed error. This SSE or other error measures are indicators of model adequacy. However there are conditions in which error measures may indicate unreliable model adequacy. Multicollinearity, an example of a real-world scenario issue, is a concern which may obscure the true results of a model and skew its accuracy.

- Multicollinearity

Human Engagement factors are highly correlated and over-lapping (Multicollinearity exists). In reviewing the literature, many topic areas which describe the human psychological and affective states over-lapped considerably. Even the physiological measures used to indicate these states were the majority of the time inconclusive and speculative in pin-pointing the specific cause for a particular response.

"Multicollinearity can have serious effects on the estimates of the model parameters and on the general applicability of the final model"

(Myers & Montgomery, 2002)

This issue of Multicollinearity can impact the results of the human engagement measures in interactive multimedia if regression analysis is used. Though if the model is used for predictive purposes, then Multicollinearity does not severely affect model predictions. In the case of this research, identifying the exact state of human engagement is most important; approximations and estimations are not desired. Thus, regression analysis which when used for system state analysis

or assessment (in the case of interactive multimedia systems analysis), can make it extremely difficult to quantify the affect of each factor on the response (in the interactive multimedia case, human engagement). FST theoretically should be a more effective approach than a regression-based model approach when modeling Human Engagement. This is contingent on the fact that an attempt to mitigate Multicollinearity is warranted. In reading other research it was found that the evaluation of the correlation of engagement with student achievement and attendance is empirically sound (NCSE, 2006).

The regression analysis approach may not be the best method to build human engagement measures models in interactive multimedia. What other choice(s) is/are there? Fuzzy Set Theory coupled with Analytic Process Hierarchy appears to be a viable solution.

- Decision Analysis: Analytic Hierarchy Process (AHP)

Humans make decisions on a continual daily basis. According to Saaty, human decisions are not made in an absolute context. Conversely, humans use relative and subjective approaches when making decisions. AHP was designed to mimic the actual decision- making process of human beings. Saaty's AHP, is a method that can be used to assign Relative Significant Weights (W_i) when prioritizing decision factors. Relative Significant Weights are usually derived by querying SME's on topic areas of interest within the AHP. This querying process is key to the theory of AHP. The associated complex logical and decision making process of people, in its simplest form, can be modeled as a string of simple pair-wise comparisons of two items (in our case the Relative Significant Weights of factors that impact Human Engagement) of interest, according

the base theory of AHP as developed by Dr. Thomas Saaty in the 1970's (Saaty, 1980). The examinee/surveyed assigns relative weights of importance to the pair-wise comparison of one factor compared to the other. Dr. Saaty created a scale of relative importance based on integers between 1 and 9 that describe the degree of importance between the pair-wise comparisons (Saaty, 1980).

Table 4 Degree of Relative Significance Definitions

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

The next pair-wise comparison of items is conducted and the procedure is repeated as with the prior set of comparisons. The results are numerical ranking of significant factors relative to each other. The following process characteristics are prime candidates for AHP usage:

1. Lacking or Incomplete Historical Data
2. Limitations on Measurement Accuracy
3. Environments with a relative high degree of Uncontrollable Variation
4. Complex Systems that may exceed the expertise of Administrators

(Butler, 2005)

Priority Discrimination, basically referred to as priority ranking of alternatives or criteria, will be utilized in calculating the Fuzzy Model weighted coefficients. The Expert Choice® software, created by Expert Choice, is one of the most highly respected decision-making theory based software packages available which is solely based on AHP theory. Badiru and McCauley-Bell will be highlighted for their application in the coupling of AHP with FST to produce Fuzzy mathematical models. So, the second part to creating the Fuzzy mathematical model utilizing FST will be discussed in the next section.

- Fuzzy Set Theory (FST)

Using AHP to assign Relative Significant Weights to factors of interest has been discussed. Now using Fuzzy Set Theory to determine the level of existence of the factor of interest constitutes the second part of the two-fold process. Why should we use FST? FST was created to address such concerns of system complexity by transforming complexity into a manageable discrete concept (McCauley-Bell & Crumpton-Young, 2005). "Fuzzy Set Theory, also referred to as Soft Computing or Fuzzy Mathematics, is a mathematical and philosophical methodology created by Dr. Lotfi A. Zadeh, and made notable by his early published work of the 1960's, "Fuzzy Sets", in

which he attempted to create a context for understanding uncertainty, complexity, and subjectivity, also referred to as vagueness" (Butler, 2005). Issues of process complexity mainly, factor multi-dimensionality, is adequately addressed through the use of Fuzzy Set Theory. Also, causal relationships are more readily identified when using Fuzzy Set modeling techniques. Fuzzy Set theory will be addressed in more detail in the following sections.

Such common real world issues of imprecision under non-ideal conditions exist in all systems that involve human interaction, especially in interactive multimedia environments. Major arguments exist pertaining to the foundational theory of FST. One such argument in the literature against the use of Fuzzy Set usage states that classical probability theory can be used in lieu of FST to address problems via a similar approach. However, the fundamental argument overlooks the foundational differences in theory between FST and classical probability approaches. FST addresses the issue of "the degree of existence" not "the likelihood of occurrence" addressed by classical probability theory.

In contrast to FST, Classical Discrete Set Theory, founded in classic Greek philosophy, discusses logic or set theory in a definitive absolute context with very minimal room for ambiguity. Fuzzy methodologies are becoming common practice in the world especially in Japan, where successful cases are being documented on a continual basis. Other forms of Fuzzy usage and reliability are embedded in the theory.

Methods for ensuring model reliability consist of the use of Cronbach's alphas, as with many query and questionnaire-type instruments. The degree of existence of a factor should not be heavily influenced by any one subject's perspective or other highly variable sources of error. Greater detail, of the mathematics of FST will be provided in the following chapters that focus on Fuzzy Mathematical model development.

- Alternative Cognitive Models

The literature provided insight into quantitative mathematical models and algorithms from various industries that may prove beneficial to this research. Quantitative models in the arena of Human Engagement Modeling, Interactive multimedia, Cognitive Learning theory, tend to exist in lower numbers than qualitative based models and frameworks, yet there are some which may be applicable. For instance, the following table and narrative will provide examples of diverse models and how they may be applied to this research.

Table 5 Quantitative Human Cognitive Models

Model Name	Contribution	Application Environment
Counterfactual Models	Refers to how things may be if specific conditions existed. This could be quite beneficial in reference to human perception.	Learning/Logic Systems
Fitt's Law Models	Can potentially be used to predict time to learn a task; Though may not be directly applicable to defining Engagement.	Human Computer Interaction (HCI)

Model Name	Contribution	Application Environment
Classical Test Theory Models	A simple method that can be used as a guide rather than a prediction tool for individual human performance analysis can be beneficial in standards creation.	Cognitive Psychological
Attribute Hierarchy Method	Can be used to assess cognitive level of subject based on hierarchy of interrelated task performances.	Cognitive Psychological
EPIC	Models multimodal and multiple task situations well. Future research in a true MMORPG environment would benefit from model usage.	Human Computer Interaction (HCI)
Soar, EPIC-Soar	Good for modeling large problems. Level of required programming software expertise may be extensive.	Artificial Intelligence (AI)
ACT-R	Newly developed lacks reliability and credibility within the research community.	Artificial Intelligence (AI)
GLEAN	Simple and fundamental implementation of cognitive theory and task analysis. Can be used to model complex scenarios also.	Human Computer Interaction (HCI)
APEX/CPM-GOMS	Another GOMS model that uses refined versions of GOMS called CPM-GOMS.	Human Computer Interaction (HCI)
GOMS	As with any model that decomposes task to thier fundamental levels, would be beneficial to this research.	Human Computer Interaction (HCI)
MicroSAINT IPME/MS-HOS	Focus on psychomotor and limited much support of cognitive and psychological aspects without extra effort. Would lend very limited contribution to current research.	Human Computer Interaction (HCI)

Model Name	Contribution	Application Environment
Item Response Theory (IRT) Models	A subject's past ability may be useful in modeling future Human Engagement may incorporate elements that delineate dynamic cognitive development due to time or growth (as in the case of children's cognitive ability/capacity versus that of an adult)	Cognitive Psychological

The following narrative explains the aforementioned mathematical models in more detail.

Counterfactual Models

Model Application Type: Cognitive (Logic Reasoning); Counterfactual models are based on causal dependencies. For instance, if a hypothetical condition, state, or scenario is counterfactually related to an existing "real world" phenomenon, then the existing "real world" condition, state, or scenario should change if there is a conditional change in the hypothetical event. If there is no conditional change in the hypothetical event, then the existing "real world" condition, state, or scenario should remain the same. The technique is entrenched in conditional probability theory and causal dependency networks.

Fitt's Law Models

Model Application Type: Adapted (Human Computer Interactions, HCI); Mainly used to predict motion and movement along a single dimension in Human Computer Interactions, it may be possible to model Human Engagement as a path consisting of two points with the start point being "no engagement" and the endpoint being "engagement".

Fitt's Law can be expressed in the form of the

$$T = a + b \log_2 ([D/W] + 1)$$

Where:

T = Average time to complete movement

a = Start/Stop time

b = Speed or rate of progression

D = Distance from start point to center of target

W = Width of the target

Classical Test Theory (CTT) Models

Model Application Type: Cognitive (Psychometric); Classical Test theory based models utilize psychometric theory to predict the outcomes of psychological based tests. CTT is relatively simple in structure. The technique utilizes empirical data about the success rate of the population of interest. A limitation of CTT is that inferences about individual results are sample dependent.

Attribute Hierarchy Method (AHM)

Model Application Type: Cognitive (Psychometric); The AHM is a psychometric method for classifying examinees' test item responses into a set of structured attribute patterns associated with different components from a cognitive model of task performance (Gierl, 2007).

EPIC

Model Application Type: Cognitive; EPIC is a production system (software) cognitive processor that incorporates perceptual and motor processors to address multimodal task situations. Quantitative models of Human Engagement can be created for multi-tasking scenarios. EPIC is highly customizable which may be a pro and a con due to limited technical support. Though many pros exist yet a major limitation is its lack in capability to model long-term memory and retention.

Soar, EPIC-Soar

Model Application Type: Cognitive; Soar is a human performance modeling production system that is based on GOMS (see GOMS below). This can be used for complex rule sets. The model emphasizes cognitive activity in a problem-solving context. One major drawback is the menial use of substantiated psychological theory

ACT-R

Model Application Type: Cognitive (AI); ACT-R is based on neural-net related control rules. The model is grounded in cognitive neuroscience theory. Heavy emphasis is on human cognitive modeling. ACT-R is based on conditional probabilities that activate decision rules. Within ACT-R specific rules are then strengthened as successes are attained. This type of modeling is still in a nascent state, thus lacks the credibility of other models.

GLEAN

Model Application Type: Cognitive; GLEAN is a cognitive modeling architecture derived from GOMS. It is well documented. Issues of adequate training and software support exist.

APEX/CPM-GOMS

Model Application Type: Cognitive (HCI); APEX may allow for rapid model production and utilizes a general-purpose simulations engine. The psychological theory based elements are lacking. CPM-GOMS theory allows for multitasking modeling and does not assume cognition as merely a serial process.

GOMS (Goals, Operators, Methods, and Selection Rules)

Model Application Type: Cognitive (Psychomotor, HCI); GOMS utilizes an approach which decomposes high level tasks into fundamental incremental tasks. These incremental tasks can then be studied and grouped according to whether they are related to Goals, Operators, Methods, or Selection Rules. Quantitative results are then derived based on observations of resultant measures.

MicroSAINT IPME/MS-HOS (Integrated Performance Modeling Environment)

Model Application Type: Limited Cognitive (Psychomotor); MicroSAINT IPME incorporates a Discrete Event Monte Carlo based Simulation Engine. There is lack in the cognition versus the emphasis on operator psychomotor results.

Item Response Theory (IRT) Model

Model Application Type: Cognitive (Psychometric); IRT is a statistic based modeling method that is based on the assumption that the probability of answering a question correctly is a function of some ability or characteristic internal to the test taker. This technique is hinged on previous personal experience and outcomes. For example, the probability of answering an item correctly is:

$$p_i(\theta) = c_i + [(1 - c_i)/(1 + e^{-ai(\theta - bi)}]$$

Where:

θ = The person's ability Parameter

a_i = item parameter, such as question difficulty

b_i = item parameter, such as question difficulty

c_i = item parameter, such as question difficulty

In summary, the Analytic Hierarchy Process coupled with FST can be used to mitigate the impact of multicollinearity found in the regression analysis approach. Also various models from other industries may prove beneficial to his research. In general, Human Engagement measurements can become ambiguous and vague. In order to clarify such issues from the literature, the psychology and human cognitive approach will be addressed in the next section.

Psychology and Human Cognitive Sciences

The Psychology of interactive multimedia addresses the ways in which humans interface computer and video games from a mental/cognitive perspective. The following relevant topic areas to be considered in this research include:

1. Engagement Definition
2. Psychometric Scaling
3. Physiological Measurement: Neuro-feedback
4. Learning (Engagement) Theory

Also, within these topic areas notable key personnel and contributors to the Psychology body of knowledge include:

1. Dr. Rensis Likert
2. Dr. Carl Gustav Jung
3. Dr. Volney Mathison
4. Dr. Richard Caton
5. Dr. Hans Berger
6. Dr. Donald Kirkpatrick
7. Dr. Robert M. Gagné
8. Dr. Marcy P. Driscoll

This literature review was quite expansive from the Psychology perspective. In order to ensure concise research, specific topic areas were addressed. The next section will provide a basis of discussion for these pertinent topic areas.

Commentary

- Engagement Definition

The majority of the literature addresses human engagement from a human cognitive perspective. Deimann states that a potential problem or gap in the body of knowledge is that the literature has been dominated by cognitive approaches in interactive multimedia and multimedia applications (Deimann & Keller, 2006). When we speak of cognitive we refer to the "What" humans do in contrast to the "Why". So, engagement has traditionally been defined as activities that are related

to the conscious act of thinking, problem-solving, memorizing, recalling, and understanding. Measurement of engagement in terms of cognition has included various methods. Psychometric scaling happens to be one of the most prevalent approaches.

- Psychometric Scaling (Likert Scales)

Quantifying activities such as thinking, memorizing, recalling, and understanding, is extremely complex. Some approaches to quantifying such cognitive activities have become known as Psychometric Scaling (Likert, 1932). In summary, Likert scales allow a participant to express his/her level of experience usually in the form of agreement, partial agreement, or disagreement with the question of interest. The literature states Psychometric scales help identify correlation that exists between variables of interest. This differs from more quantitative based research which attempts to draw causal relationships between variables of interest such as in regression analysis. Please note that there is a distinct difference between correlation and causal relationships. Most times qualitative based research such as human attitudinal, opinion-based, or behavioral studies are not causal in nature. However, the qualitative research data contains valid information which can be used to aid in the drawing of valid conclusions. Likert Scales are widely known and used amongst scientists as a type of Psychometric scale, though uni-dimensional in nature (Likert, 1932). This is a somewhat limitation when quantifying complex cognitive activity since such a scale cannot adequately capture the complexity of a factor such as human engagement. A multi-dimensional scale approach is much more desired. Psychometric approaches most often include questionnaires and surveys.

In the literature measurements of engagement were overwhelmingly accomplished through the use of questionnaires/surveys, though on their own, these methods are methodologically unsound (Slater, Brogni, & Steed, 2003) since the very mentioning of a phenomenon may bring about its existence. Questionnaire data, alone, is questionable and should be supplemented with other measures. Hence, the contemporary approach would be to theoretically merge this qualitative data with physiological response data to define factors, such as engagement. Also, traditionally, questionnaires were usually administered after exposure to a stimulus or event. This requires that a participant recalls (remembers) an experience; during recall, multiple cognitive processes are enabled thus increasing the potential of deviation from the true event or experience. A better approach would be to seamlessly integrate qualitative questioning as part of the experience, the interactive multimedia application within this research, and as close in time as possible, to the occurrence of the phenomena of interest. Researchers such as Dillion et al. have used similar methods of merged questionnaires and physiological response data (Slater, Brogni, & Steed, 2003). However, qualitative data and quantitative data are inherently different, there must exist a type of translation that ensures a one-for-one relationship or level of comparisons in order to produce a harmonious validated model.

The field of Psychometrics is continuously evolving as the knowledge domain expands. The physiological response information that can be used in conjunction with the psychological will be discussed next.

- Physiological Measurement: Neuro-feedback

Methods have been created to measure physiological response. Research has also been conducted to find ways to predict such physiological responses in interactive multimedia environments, even without the need of cumbersome biofeedback gear (McQuiggan, Lee, & Lester, 2006). Measuring this response will allow researchers to better understand the connection between the physical and psychological state. Though there are concerns that need to be addressed when measuring physiological response. Many of these methods are invasive, meaning that they may make contact with a subject, or induce abnormal comfort levels. Other methods and techniques utilize more remote or less invasive procedures. Measurement techniques researched in the literature include:

1. Galvanic Skin Response (GSR)
2. Electroencephalography (EEG)
3. Eye Movement Tracking
4. Heart Rate Monitoring
5. Respiration

Galvanic Skin Response (GSR) utilizes a psycho-galvanometer to measure the electrical resistance of the skin when a low voltage electric current is present (Fuller, 1977). GSR was invented by Dr. C.G. Jung and improved by Dr. V. Mathison (who added amplification techniques to improve measurement readability and usability). Interpreting GSR results have been controversial and inconclusive, according to the literature. Though the GSR measurement may be interpreted as an indicator of emotional state change, further attention must be dedicated

to the specifics and source of the change in state. For instance, human emotional arousal tends to exhibit the same physiological responses regardless of which emotion (anger, fear, love, etc.). Hence, GSR measurements of different emotional states may appear similar, if not exactly the same. Though there is a known connection between the sympathetic nervous system (SNS) and human emotional state, controlled by the limbic system, as explained in the literature, however the relationship is believed to not be causal. In essence, more research must be conducted in order to understand this connection in efforts to reliably explain what happens or what a specific human psychological response means.

Electroencephalography (EEG), another neuro-feedback measurement method, measures brainwave activity. The method included the connection of sensors (electrodes) on the scalp and sometimes in a sub-dermal manner. The earliest history relative to the discovery of EEG was in the mid to late 1800's by Richard Caton (Fuller, 1977). The belief is that a physiological response, in terms of various brainwave activity (electrical impulses), results when psychological activities are enacted. In summarizing the literature review, EEG wave groups can be labeled as:

- Alpha: 8 - 13 Hz. (Associated with relaxed awareness and inattention)
- Beta: 14 - 26 Hz. (Associated with conscious decision-making and attentiveness)
- Delta: 0.5 – 4 Hz. (Associated with deep sleep activity)
- Theta: 4 – 7 Hz. (Associated with unconscious activity and deep meditation)

Concerns exist in the interactive multimedia environment that human perception can be impacted due to the invasive nature of EEG. Modern techniques are continuously under development in

order to mitigate arousal and stress responses due to body contact based biosensor usage. In this case, advances in remote non-contact sensor usage prove beneficial. Eye-tracking methods are some of the more contemporary methods that observe human eye movement and the connection to emotional arousal and the psychological state. As quoted by early researchers, "Early eye trackers were cumbersome devices in which the user wore uncomfortable gear, such as bulky helmets or other equipment affixed to the head" (Wilder et. al., 2001). Advances in remote (non-contact methods) eye-tracking technology can be attributed to advances in photo/video technology and computing. These non-contact methods are non-invasive since the eye-tracking apparatus is not attached to the body of the subject. Infrared cameras are usually used to monitor eye position. On the other hand, contact methods, which require that the eye-tracking apparatus to contact the subject's eye are extremely invasive. This is so much so that local anesthesia must be administered thus minimizing the duration of experimental sessions to less than 20 minutes at a time (Wilder et. al. 2001). Barring this limitation, the important unit of measurement in eye-tracking to be used in this research is known as the saccade. Saccades are jumps in ocular fixation from one stationary point to another. It is hypothesized that the duration of a saccade (dwell-time, fixation, or gaze) can indicate a point of interest or even possibly a lack of engagement. Also, the number of saccades in a time period, saccade frequency, can indicate arousal or relaxation. Overall, the literature supports, including authors such as Bahill and Stark, that two-dimensional eye-tracking can be accomplished by video-based, non-contact eye-tracking methods. In interactive multimedia, the use of a two-dimensional video output mechanism is most common as a subject interfaces a game stimulus.

The next two sections will address heart rate monitoring and respiration, called cardiopulmonary events. Firstly, in addressing heart rate monitoring there are various methods that are used to observe heart rate. The most relevant to this research are as follows:

1. Blood Volume Pulse (BVP)/Heart Rate: Determines heart rate via amount of blood just under skins surface in a sample area at a specific time.
2. Auscultation: Listen to heart beat via stethoscope
3. Arterial Pulse: Assess heart rate via pressure (pulse) in arteries
4. Electrical Impulse Monitoring: Monitors and translates electrical impulses produced by cardiac activities into observable analog or digital signals.

(Berntson, Quigley, & Lozano 2007)

The heart is controlled by the autonomic nervous system (ANS) via the sympathetic nervous system (SNS), a branch of the autonomic nervous system. In response to stress or arousal, the SNS manages various responses, such as the "Fight or Flight" response; the heart rate changes in order to prepare the body for action. Hence, research has shown that there is a connection between changes in heart rate and level of engagement; engagement as defined by attentiveness or cognitive activity enacted. "Because physiological responses are directly triggered by changes in affect, biofeedback data such as heart rate and galvanic skin response can be used to infer affective changes" (McQuiggan, Lee, & Lester, 2006). So, of the aforementioned methods to monitor heart rate, BVP/Heart Rate appears to most readily and appropriately addresses the requirements of measuring human physiological responses in interactive multimedia and is generally used in research as stated by the literature. One method of BVP measurement utilizes

photoplethysmographs (PPG), i.e. emitted infrared light, to determine the amount of blood near the skin's surface. This information can then be used to determine the heart rate. The amount of cardiovascular information derived through the use of BVP exceeds that of the other methods mentioned. Not only is there information about the pulse peaks, but about activity that occurs between the pulses can be ascertained. BVP will be discussed in more detail in the following chapters. The other closely connected event to heart rate, respiration will be discussed.

Respiration is connected to cardiovascular activity. A couple of respiration monitoring techniques was researched in the literature and can be classified according to various criterions. The following respiration or ventilation monitoring methods were observed:

1. Respiratory Sinus Arrhythmia (RSA) Analysis
2. Inductive Plethysmography
3. Carbon Dioxide (CO_2) Concentration Analysis

RSA exists because of the relationship between cardiopulmonary activity heart rate and respiration rate. RSA measurement is widely accepted in assessing heart rate, and in-turn human psychological state. Nevertheless, RSA can be considered intrusive in nature; in addition quantification techniques can be somewhat inconsistent according to Denver et al. (Denver, Reed, & Porges, 2007).

According to the literature, Inductive Plethysmography has long been found to be a standard, well-validated and accurate estimation procedure of both timing and volumetric variables in the

laboratory (Grossman, Spoerele, & Wilhelm, 2006). Yet, the use of a strain gauge or device that constricts that body may prove uncomfortable. Hence, the use of CO_2 Concentration Analysis is a viable measurement option in which a sample volume of air is monitored over a specified time period.

As a subject respires, changes in the CO_2 Concentration within the sample volume of air can be recorded. Such increases in CO_2 may indicate greater respiratory activity, and possibly increased arousal. Such a method is non-invasive.

Merging physiological response data with human perception qualitative data may produce more enriched information about what has been observed. Hence the potential major shortcomings of both physiological and perception measurements may be mitigated. So, how do we define the cognitive ability of human beings? Learning theory contributors have addressed this type of question which is part of the foundation of the Human Engagement definition within this research.

- Cognitive Learning Theory

In this conducted literature review many factors were identified that may impact student achievement (Human Engagement), the educational experience, and training outcomes (with interactive multimedia effectiveness as the main outcome of interest). Cognitive gains or losses, are types of responses affected by these factors, are more closely associated with student achievement i.e. successful mastery of learning objectives. Cognitive gains were observed in

many of the interactive multimedia studies; from another perspective, the focus on Human Engagement, within the literature. For instance, in numerous studies summarized by a meta-analysis which included 32 interactive multimedia studies performed by J.J. Vogel and others (Vogel et al., 2006) found that high perceived participant control of navigation in interactive multimedia applications positively impacted cognitive gains (Deimann & Keller, 2006; O'Neil et al., 2005). On the contrary, though there exists research which raises the issue that the exhibited cognitive gains observed in interactive multimedia are not solely attributed to the fact of the presentation of educational and training content in a game-based format, but the gains are due to the existence of a solid instructional design methodology embedded within the gaming application (Gee, 2005). So, to ensure a founded instructional design methodology exists, attention must be given to various aspects of the interactive multimedia application, equally, in addition to the graphical application design. However, to examine and define human engagement from only a cognitive perspective is rather limiting. There is a need to address the psychological, social, and emotional aspect. Gee presented some examples of well designed games that cause people to want to play more, and spend more money just for a challenge. Games such as "The Rise of Nations", "Deus Ex", "The Elder Scrolls III: Morrowind" have proven popular amongst gamers. Apparently such games exhibited a founded instructional design methodology in addition to game graphics and usability features. Instructionally sound games tend to address Robert Gagné's Conditions of Learning Theory quite adequately. Part of this theory includes an instruction design guide that delineates nine instructional events theorized by Gagné:

1. Gaining Attention
2. Informing learners of the objective

3. Stimulating recall of prior learning
4. Presenting the stimulus
5. Providing learning guidance
6. Eliciting Performance
7. Providing Feedback
8. Assessing performance
9. Enhancing retention and transfer. (Gagné, 1985)

Existence of each of the aforementioned elements can be observed in good games. Kirkpatrick's four levels for evaluating training model, also includes some common elements of Gagné's theory. Kirkpatrick's Four Levels include:

1. Level 1 Reaction (comparable: Gaining Attention, Presenting the stimulus)
2. Level 2 Learning (comparable: Eliciting Performance during training)
3. Level 3 Behavior (comparable: Eliciting Performance after training, Enhancing retention and transfer)
4. Level 4 Results (comparable: Assessing performance after training)

Further detail of Kirkpatrick's model defines Reaction as (Level of Satisfaction), Learning (Attitude change evidence of skill increase/decrease), Behavior (Job change transfer of knowledge), and Results (How training organization benefited from training involvement) (O'Neil et al., 2005). Yet, for this interactive multimedia research the learning theory had to address lower-level Human Engagement details.

Other learning theory models exist such as theorized by Baker and Mayer. The Baker & Mayer's CRESST model of Learning (O'Neil et al., 2005) appears to be a suitable framework to support the creation of a Human Engagement definition, since it provides a micro-level view versus the widely known macro-level view approach of other cognitive frameworks such as Kirkpatrick's learning framework. The five identified factors (families of cognitive demands) of the CRESST model include:

1. Content Understanding
2. Collaboration or Teamwork
3. Problem Solving
4. Communication
5. Self-Regulation

These factors can indicate the level of impact on the user's educational experience. As aforementioned, the MMORPG environment can be considered as designed to incorporate CRESST model elements. The CRESST model, created at the University of Southern California/National Center for Research on Evaluation, Standards, and Student Testing (CRESST), US; UCLA/National Center for Research on Evaluation, Standards, and Student Testing (CRESST), US, will be used extensively within this research. CRESST will form the foundation of the Human Engagement definition. Recent history, past 15 years, of empirical data on video/computer games as effective teaching tools has not supported the notion of interactive multimedia training applications as providing a significant advantage over traditional educational

and training methods as determined using traditional evaluation methods. The interactive multimedia technology research shows promise, even though most of the empirical studies on game-based training effectiveness have consisted of disjointed and decentralized efforts across studies. A possible reason for the lack of empirical evidence is that common accepted methodologies across the industry are still nascent. So, determining game effectiveness, documented as the intensity or longevity of engagement according to O'Neil, would be beneficial to the body of knowledge. Baker and Mayer's CRESST model may be used to evaluate the level of Human Engagement in interactive multimedia environments. That, while the cognitive-based approach of the CRESST model provides the foundation of this research, it has been deemed that an augmented model, created as a result of this research, be used that incorporates the CRESST methodology and Human Engagement factors. Learning theory will not be directly studied in this research; however the quantity and detail of learning theory literature will provide insight into defining the factors that impact Human Engagement.

Learning theorists have different views of learning theory. Cognitivism, which explains behavior in terms of cognition and higher-level thinking, is in theory supported by the CRESST model. The next section will address another theory, Constructivism which centers the learner as the controller of the path to learning.

Researchers such as Wenglinsky appear to support a more constructivist/inquiry based learning theory and agree that interactive multimedia and other training technologies are better suited for "self-efficacy" and self directed learning (Wenglinsky, 2005). Why is this important?

Constructivism allows for the learner to construct new knowledge from the past knowledge of personal experiences and events. In a virtual environment, such as afforded by interactive multimedia, learners progress at different rates and perceive experiences from different perspectives. Though this "Real World" approach seems logical, critics cite problems that can occur from the constructivist-based theory.

Some identified problems of learning including, constructivist theory, are possibly due to the nature of constructivism discovery/inquiry based higher-level reasoning. Researchers such as O'Neil state that there are human cognitive limits that exist. Cognitive Load Theory (CLT) attempts to explain these cognitive limits. Cognitive Load Theory as theorized by John Sweller addresses the existence of a finite short-term memory and a relatively infinite long-term memory. Working Memory (in the short-term is limited) can be impacted by cognitive overload. Cognitive overload can occur when too many tasks are required to be completed simultaneously or poorly developed instruction exists. Overall, the key to good instructional design and a positive learning experience is predicated on the fact of multiple factor awareness.

The cognitive approach to human psychology has become an important area of contribution to the literature; though other topic areas should be addressed to ensure new discoveries and increased knowledge. Also, the area of the social sciences as an extension of psychology will be discussed in the next session. Psychology and sociology are related in many ways. Many of the measurement methods, such as psychometrics, are used in other social sciences.

Social Sciences

The relevant topics of the research from the Social Sciences perspective of interactive multimedia technology will consist of the following four topic areas within this body of work:

1. Engagement Definition
2. Socio-cultural Theory in Gaming
3. Social Interaction and Collaboration

Key personnel and institutions which were major contributors in the literature review are as follows:

1. Dr. Jean Piaget
2. Lev Semyonovich Vygotsky
3. Dr. John Dewey

Please note that the listed contributors are in essence an extension of the previous section on Psychology. Thus, many of the same persons are noted in the literature for contributions that may overlap fields of study including, psychology, social sciences, and management theory. The following commentary will highlight the distinct contributions of each contributor and the relevance to the literature.

Commentary

- Engagement Definition

Engagement in the social context addresses the interactive multimedia environment as an extension of the real world (society). There are symbols that represent concepts and a forgiving environment that allows for failure without drastic repercussions. The participant, seeks to test obtained knowledge, construct new knowledge and apply knowledge which may be helpful to understanding the at large community. The individual is part of the social construct. John Dewey's theories of play reiterate the belief that the human experiences and level of engagement within the interactive multimedia environment prove pivotal in the establishment of the learning foundation. In essence, engagement is the interaction within an environment, governed by a social construct and protocol which in-turn provides knowledge fit for application in society external to the interactive multimedia environment.

- Socio-cultural Theory in Gaming

There is a common theme that exists when describing the active participant of interactive multimedia environments and their interaction in a team, community, or society. Researchers of the topic the role of play in human development, Piaget, Vygotsky, and Dewey are most frequently cited within the interactive multimedia literature (Dipietro, Ferdig, Boyer, & Black 2007). Though a common interest exists within their research, each contributor's theories contain somewhat noticeable differences in philosophy. For instance, Vygotsky's theory of "Zones of Proximal Development" (ZPD) presents challenges in which cognitive adjustments existed based on the social environment. In essence, the level of cognitive development may be impacted by the social context. In the next section we will see how Piaget's theory contrasts with ZPD.

Piaget's Development Theory focuses on the individual, as the pure center of knowledge, and then addresses knowledge acquisition and construction as a somewhat disjointed activity from the social context. Such a theory, in essence, opposes that of Vygotsky's ZPD. Piaget's work with children addresses the various developmental stages of human cognitive development from birth up unto adolescents. As we can see, Piaget's perspective is quite reminiscent of the cognitive-dominated literature.

Hence, a common framework for electronic gaming research utilizing the context of sociology is much needed due to the complexities of diverse platforms, games/genres, and design intentions.

- Social Interaction and Collaboration

Social interaction in gaming, especially the MMORPG, is a very prevalent and pertinent aspect of interactive multimedia technology. Society has noted the influence of gaming on people, mostly negative concerns such as increased real world violence due to increased virtual world violence. However the evidence is rather weak in attempting to support such a believed strongly correlated relationship. "Baldaro, Tuozzi, Codispoti, Montebarocci, Barbagli, Trombini, et al.(2004) provide a physiological account demonstrating the effects of violent electronic games which result in increased arterial pressure and anxiety levels, but not in hostility levels" (Dipietro, Ferdig, Boyer, & Black, 2007). In summary, the physiological effects of gaming have resulted in noticeable attitudinal and physical changes but no hostile effects have been supported; these results show apparent inconsistencies when attempting to apply Vygotsky's ZPD to electronic interactive multimedia, where the gaming environment is perceived most influential.

Cognitively speaking, ZPD states the possible belief that the sense of reality mimics that of the virtual reality. Even research produced via the Game Developer's Conference 2007 (GDC) delineates the weak correlation between player personality and in game identity/personality. Another aspect of the social influence of gaming addresses the aspect of feedback within a protected social construct.

User feedback, specifically immediate feedback, impacts the level of educational experience. The game-play of Serious Games provides a safe protected environment that mitigates the consequence of failure (Pannese & Carlesi, 2007). This idea of active failure based feedback is instrumental in encouraging users to continue playing and increases the amount of time a participant is exposed to the game application. Aspects of feedback can also be applied to areas of collaboration and communication. User presence, collaboration, or the perception of "playing alone together", in MMORPG environments, impacts the user experience as there is connection between the cognitive and the physical experience (Slater, Brogni, & Steed, 2003; GDC 2006; GDC 2007). Collaboration, though quite pertinent to the social aspects of gaming, research has shown individuals tended to exhibit greater cognitive gains than groups (Vogel et al., 2006). So, if structured correctly, functional collaboration creates immersion and is needed in game designs (GDC, 2006).

The social science perspective of interactive multimedia provides a valid perspective of engagement. The very foundation of play and gaming hinges on the social research of human development.

Industrial and Systems Engineering

Industrial and Systems Engineering areas of study provide important information about topics that have expanded from the manufacturing of goods arena, to services of all types. Relevant topics to interactive multimedia reviewed within this research include:

1. Engagement Definition
2. Quality Standards and Metrics
3. Human Work Measurement

Within the aforementioned topic areas key personnel and institutions have contributed to the body of knowledge. Some of these contributors include:

1. Frederic Taylor
2. Dr. W. Edwards Deming
3. Dr. Joseph Juran
4. Armand Feigenbaum
5. Philip Crosby
6. National Institute of Standards and Technology (NIST)
7. International Organization for Standardization (ISO)
8. American National Standards Institute (ANSI)
9. American Society For Quality (ASQ)

The commentary will address these topic areas, mainly the quality philosophy within this body, and how they impact interactive multimedia application.

Commentary

- Engagement Definition

Engagement from the Industrial and Systems Engineering perspective in relation to interactive multimedia, addresses a more integrated approach by incorporating multiple aspects of engagement into a single coherent definition. Most notably, work measurement and labor standards, that correlate to Human Engagement in the literature, is a methodology and set of tools used to identify and monitor human action and the pursuit of a goal. This use of management tools, such as mathematical modeling, enables a systems administrator to act based on data, including Human Engagement data. The systems approach to defining human engagement may examine the subcomponent factors that impact engagement and establishes a framework that incorporates these factors by delineating their interconnectedness and explains how they contribute to the higher level goal (response) of human engagement. Management tools and methodologies, such as quality standards and metrics development, facilitate greater effectiveness and efficiency when the improvement of human engagement is warranted.

- Quality Standards and Metrics

Quality Standards and metrics development provide important management tools be it in the manufactured goods production sector or in services. The topic of Quality has garnered much attention, especially within the services arena, within the past 30 years or so. Advances in quality philosophy implementation within the manufacturing arena have been realized in other non-manufacturing areas such as healthcare systems, financial systems, and educational systems. This research will focus on interactive multimedia/educational systems quality standards

implementation. What is quality? Quality is defined as "The totality of features and characteristics of a product or service that bears on its ability to satisfy stated or implied needs" (Heizer & Render, 2006). Later in this document there will be commentary on educational systems standards. The discussion will highlight the evolution of quality standards-based education and training.

Deming, Juran, Feigenbaum, and Crosby, are arguably the most notable modern Quality gurus and have been considered the fathers of modern Quality philosophy. Heizer & Render states that America's more recent involvement with quality came as a direct counter-maneuver to remain globally competitive in the production of manufactured goods. International competition such as from Japan, directed attention towards higher product quality, increased profits, and greater customer satisfaction. So, as evidence of a commitment to quality and its importance, the United States government instituted programs and organizations that promote quality initiatives in production & manufacturing, healthcare, services, and educational systems administration (Butler, 2005). Government officials saw the need to get involved concerning the quality movement. Their reaction lead to the Malcolm Baldrige National Quality Improvement Act (Public Law 100-107) created in 1987 as a form of legislation to make American businesses and the public aware of the importance of quality. This award recognizes five different types of organizations including educational organizations and is administered by the National Institute of Standards and Technology (NIST). The American Society for Quality (ASQ) is another such organization created to address American concerns quality. On the international front, the International Organization for Standardization (ISO), has engendered a global view of quality.

Organizations such as American National Standards Institute (ANSI) and ASQ were instrumental in publishing quality assurance standards currently known as the ANSI/ASQ Q9000 series, which is the American version of the global ISO 9000 standards (Heizer & Render, 2006). Such quality standards and initiatives have been touted by practitioners, researchers, and businesses as the culprits of increased product and service quality of manufactured goods and services world-wide. Quality certification has proven to be rather successful. Quality philosophy can be applied to anything including Human Engagement in interactive multimedia environments.

- Human Engagement/Work Measurement

Frederic Taylor's Scientific Management as published in 1911 still provides insight for work designers of the 21st century. The time study can be used to determine the appropriate actions needed in order to correct problems, improve operations, or predict outcomes. Though the true physical labor aspects of interactive multimedia (since interactive multimedia is cognitive based) differ from those of Scientific Management, the framework of analysis is of interest. Heizer & Render summarize the foundational steps in creating a labor standard as follows:

1. Defining the task to be studied
2. Divide the task into precise elements
3. Decide how many times to measure the task
4. Time and record elemental times and ratings
5. Compute the average observed time
6. Determine performance rating

7. Add the normal times for each element to develop a total normal time for the task
8. Compute the standard time (provides for allowances, like fatigue, personal time, and unavoidable task delays)

The Task Analysis is an integral part of standards and metrics creation. Understanding the elements of a task will allow for deeper understanding of that task. Areas such as education and training have implemented this idea of the task analysis as a result of Taylor's work. Training systems theory expands the task analysis to incorporate main higher-level categories such as Functional Objectives, Conditions of Task Performance, and Tasks & Behaviors (Butler, 2005). Such an analytic framework would seemingly help organize observations and aid a researcher in interpreting human engagement responses more accurately.

Improving Human Engagement incorporates ideas of quality standards and continual improvement. The identification of tasks or actions that lead to diverse levels of Human Engagement is pertinent to the understanding of how engagement can be improved. The human element of the task analysis will be discussed in the next section.

Human Resource Management

The following relevant topics were researched in order to attain a greater understanding from the perspective of Human Resource Management field of study in reference to interactive multimedia:

1. Engagement Definition
2. Motivation Theory
3. Volition Theory
4. Management

There exist key personnel and institutions that are known for their contribution to the field of Human Resource Management. Mainly, this discussion will address contributions on the topic of Motivation. Contributors are noted as follows:

1. Dr. Burrhus Frederic (B.F.) Skinner
2. Dr. Abraham Maslow
3. Dr. David McClelland
4. Dr. John M. Keller
5. Dr. Raymond J. Wlodkowski
6. Dr. Julius Kuhl
7. Dr. Douglas McGregor

Insight from these contributors will be explored in the following section. We will see how these Human Resource Management concepts may be applied to interactive multimedia.

Commentary

- Engagement Definition

Defined human engagement from the perspective of Human Resource Management describes engagement as the capturing of human interest (Keller, 2002). This level of interest in turn impacts the level of Human Engagement. This concept may be somewhat subjective in nature be it that personal experience is highly variable across diverse personality types.; what things interest one person may in turn bore another person. Engagement is connected to motivation. In essence, the concept of motivation theory applied to multimedia applications is relatively recent and the body of knowledge is in need of continued development (Deimann & Keller 2006).

- Motivation Theory

The literature addresses the topic of human motivation from both a more general and broad approach and even at a granular motivation framework level. Aldag & Kuzuhara describe motivation as the moving to action or the arousal of an individual towards a desired goal or behavior (Aldag & Kuzuhara, 2002). Ultimately at the center of motivation is goal attainment. In building on this definition of motivation, Keller, with consensus of the majority of researchers in the field, details the general view of motivation theory and speaks of Extrinsic versus Intrinsic motivation. Traditional pedagogy has focused on the aspect that the participant is internally motivated (Intrinsically). Hence, it is the participant's responsibility to "take interest" in the instructional content. Surely the participant realizes the importance and relevance of the presented instruction, right? In contrast, researchers of contemporary motivation theory have discovered that external environmental factors can impact motivation as well. Especially in interactive multimedia, content should draw the participant into the virtual environment. Motivation is ever more important especially in interactive multimedia due to the sequential

nature of gaming. Participants cannot skip game levels as if they were scanning and reading non-engaging written text. The providing of extrinsic motivation should be a common design element employed by commercial and interactive multimedia used to train application designers. Though there is limited conclusive evidence on the interconnected relationship of both intrinsic and extrinsic motivation concepts, methods have been created by researchers to help manage intrinsic and extrinsic motivation in humans (Keller, 2002). In terms of interactive multimedia, Dickey and other researchers (Dickey, 2007; Prensky, 2006; Gee, 2005) explore intrinsic motivation generated by interactive multimedia and the issue of perceived user entitlement and ownership are highlighted in the literature. MMORPG's and intrinsic motivation were explored in the literature also. Aspects of the MMORPG that differ from other types of educational games are the high level of character development according to Dickey. Character development fosters motivation and a sense of entitlement. Personal reflection is often enabled through the use of Avatars (representations of players in the virtual environment). Caution should be heeded when examining motivation in the MMORPG application environment because free choice can be motivating and overwhelming which can possibly lead to de-motivation. Social status/social capital is exhibited through character development within the gaming application.

Another topic of research interest deals with the direct comparisons of Motivational vs. Cognitive approaches in interactive multimedia. This comparison analysis is an example of a gap in the body of knowledge. There are potential frameworks that could become foundational footholds for the bridging of this knowledge gap. For instance, John Keller's ARCS Model (Attention-Relevance-Confidence-Satisfaction) is part of a methodology that addresses

motivation from a problem-solving perspective, which can be related to interactive multimedia. The ARCS model is a motivation-based instructional content design guide. The model category, such as Attention, addresses issues of Perceptual Arousal and calls attention to alternative tactics to maintain participant interest. Relevance focuses content designer attention to connecting the human experience to content. Motive is also addressed. Confidence addresses topics to ensure the participants experience is positive and promotes competence. Finally, Satisfaction, addresses the feedback and reward tactics to be employed. These concepts of motivation are very important but what happens in the presence of waning motivation? Volition theory can explain.

- Volition Theory

In the presence of waning motivation or other impediments to learning, humans have developed methods that keep them focused and on task. The term volitional refers to this ability to remain on task in the presence of learning distractions and waning motivation (Deimann & Keller 2006). Volition addresses the need to be self- actualized. Kuhl's Theory of Action Control (Kuhl, 1984) is a contemporary approach that utilizes volition theory and approaches the issue of motivation from an information processing capability. Kuhl states that even the simplest of actions are governed by self-regulation and intention. Hence, control mechanisms that hedge against competing intentions/tendencies identified within Action Control Theory include (Deimann & Keller 2006):

1. Selective Attention: shields current intention from competing tendency
2. Encoding Control: selectively encodes those features of the incoming stimulus that are related to the current intention.

3. Emotion Control: control of emotional states according to the current intention.
4. Motivation Control: selectively processes expectancy and/or value related information that supports the current intention.
5. Environment Control: control of the environment (e.g., making social commitments) to protect the current intention
6. Parsimonious Information Processing: using stop rules to terminate the generation of more and more information regarding action alternatives.

Volition is relevant to interactive multimedia, as seen in Action Control Theory, since the participant's path to a positive experience is self-regulated. Knowledge about these mechanisms can be useful to an interactive multimedia application designer.

- Management

Human needs are research points of interest when referencing management concepts. Various theoretical needs frameworks include McClelland's Manifest Needs: Achievement, Affiliation, and Power; and Maslow's Need Hierarchy: Physiological, Security, Social, Esteem, and Self-Actualization. These needs should be considered when designing interactive multimedia applications. Game applications may incorporate a couple of different methods to facilitate learning. McGregor's Theory Y, and Theory X, addresses the management of humans and motivation. Theory Y relates to the higher-level needs of Maslow's needs theory (where management and direction are suggestive). Especially in the case of an MMORPG interactive multimedia environment, a Theory Y approach to management may be utilized. Lower level

needs are not addressed in the virtual interactive multimedia environment. Therefore aspects, such as esteem and self-actualization dominate the realm of needs. The environment is overwhelmingly self-directed. Conversely, Theory X is more dictatorial in nature (where management is more directed). There are assumptions that the individual, under Theory X, has little to no ambition to attain expected goals, i.e. lacks self initiative (McGregor, 1960). These concepts of needs should be addressed appropriately. The management of the human resource is an aspect of the Human Engagement definition for interactive multimedia applications that transcend the cognitive or the behavioral, it includes motivation.

The total picture of the human experience must be kept in perspective when designing interactive multimedia applications; not only the "What", should be addressed, but also the "Why". We must answer the question, why do humans behave the way they do.

Educational and Training Systems

The following relevant topics were researched in order to attain a greater understanding from the perspective of an Educational and Training Systems administrator in reference to interactive multimedia:

1. Engagement Definition
2. Instrument and Assessment Types Reviewed
3. Qualitative Human Research Assessment Package (RAPS) Instrument
4. Educational System Standards and Metrics

Key personnel and institutions are known for their contribution to the Educational and Training Systems body of knowledge. Their research was reviewed and they are noted as follows:

1. Dr. James P. Connell
2. Dr. Edward L. Deci
3. Dr. Richard M. Ryan
4. Institute for Research and Reform in Education (IRRE)
5. National Center for School Engagement (NCSE)
6. National Center for Education Statistics
7. National Research Council
8. Institute of Education Sciences (IES)
9. U.S. Department of Education (ED)

Next is the commentary section which delineates the literature review as pertaining to this Educational and Training System's research and its relationship to interactive multimedia.

Commentary

- Engagement Definition

Defining metrics and standards, as well as identifying factors, such as engagement, has become a major concern for academia and industry. As a primary indicator of interactive multimedia effectiveness participant/gamer engagement has been viewed as a complex qualitative entity,

traditionally. Educational systems administrators define engagement differently than game/content designers, whose knowledge resides in a domain outside of the educator's. Traditionally, engagement tends to be defined in terms of:

1. Learner frequency of class attendance (truancy)
2. Learner behavior at school
3. Learner emotional state
4. Learner cognitive and academic achievement
5. Learner reaction to challenges (failure-coping strategies)
6. Learner school activity participation
7. Learner perception of self-image and others (NCSE, 2006)

Much of the engagement definition addresses aspects of the learner while they are attending the institution (in class). In addition, though the affective or emotional state of the learner may be assessed, most of the time it is at a higher more general level, rather than at the level of the learner's response as they interface the curriculum; this is a more formative mode of evaluation. According to the National Center for School Engagement report, engagement is also viewed as "Ongoing Engagement" (i.e. Behavior, Emotions, Thought Processes) and "Reaction to Challenge" (Coping Strategies of perceived failure) (NSCE 2006). Klem and Connell also support this traditional definition of engagement in terms of emotional state of the learner and the academic performance of the student. Additionally, they provide insight about the impact of disengagement, i.e. the converse of engagement, and how it apparently increases in learners as time elapses, especially nearing the graduation from secondary school. Nevertheless, the school

environment is complex, identifying what factors impact student academic achievement is ongoing. The next paragraph identifies this engagement definition when applied to an interactive multimedia topic area. Qualitative data may be collected to determine the level of learner engagement. Survey/questionnaire instruments, such as the Research Assessment Package for Schools, exist to address these views of engagement. There are many instruments that were created to assess learner engagement; some will be addressed within the following paragraphs. A survey of learner perception may include the learner's need to participate, or importance of role, to promote continued game participation, addresses issues of learner self-image. Also, the frequency of game use, or how often the learner desires to use the game application, may correlate to the education system metric of school attendance/truancy. All in all, the NCSE research shows that more engaged students are more likely to do well than marginally engaged students.

- Instrument and Assessment Types Reviewed

The following instruments which were researched included usages that addressed student behavior, socio-emotional states, and cognitive aspects of Human Engagement.

Table 6 List of Psycho-social Instruments

Instrument Name	Description
Achievement Motivation Profile (AMP)	The *AMP* is a self report inventory that allows programs to evaluate underachieving and unmotivated students, giving them a complete picture of personal factors that affect an individual's academic performance as well as identifying areas for improvement.

Instrument Name	Description
Behavioral and Emotional Rating Scale: Second Edition (BERS-2)	The *BERS-2* was developed to provide professionals with a valid and reliable strength-based instrument to assess children and youth.
California Measure of Mental Motivation (CM3)	The *CM3* is a tool for measuring the degree to which an individual is motivated toward thinking. The scales capture characteristics associated with motivation towards learning and academic performance.
Children's Institute: Teacher Child Rating Scale (T-CRS)	The *T-CRS* is a quick, extensively tested instrument that consists of 32 items assessing positive and negative aspects of a child's socio-emotional school adjustment.
Functional Assessment and Intervention System: Improving School Behavior (FAIS)	This tool is designed to enable interdisciplinary staff to systematically identify the underlying causes of student's challenging behavior, gain a clearer understanding of his or her needs, and monitor progress.
Multidimensional Self Concept Scale	The *MSCS* is a self-report scale designed to measure multiple dimensions of self –concept in six areas. The *MSCS* can be used for evaluation purposes by programs wishing to measure improvements in self-concept, where this is a stated program goal.
School Motivation and Learning Strategies Inventory (SMALSI)	Based on more than 30 years of research, the *School Motivation and Learning Strategies Inventory* (SMALSI) was developed to measure academic motivation, learning strategies, and study habits
Student School Engagement Scales	The *Student School Engagement Scales* are designed to measure three distinct aspects of student engagement: behavioral, emotional and cognitive.
Student Self Concept Scale	Based on Bandura's theory of self-efficacy, which relates specific observable behaviors to self concept, the *SSCS* documents the perceived confidence and importance of specific behaviors believed to influence the development of youth's self concept.
Teacher Emotional Support Scale	*The Teacher Emotional Support Scale* is one measure of various positive dimensions of the classroom social environment and has been found to be linked to student motivation and engagement in learning.
Research Assessment Package for Schools (RAPS) Instrument	*The RAPS* instrument can be used to facilitate school reform. It addresses administrator, teacher, staff, student, and parental perception.

The list of instruments lends viable information for the creation of a interactive multimedia instrument that could capture human perception. The next section will consist of detailed information about the Research Assessment Package for Schools instrument.

- Qualitative Human Research Assessment Package (RAPS) Instrument

The Research Assessment Package for Schools (RAPS) Instrument, more specifically the RAPS-SM instrument designed for middle school students, proved to be the best choice of the reviewed instruments. It was multi-faceted in its approach in assessing human psychological, social, and emotional state, most notably, human engagement. Also, its structure consisted of concise question/statements that addressed key areas of the engagement definition and required students to answer question/statements in terms of relative truth of statement accuracy in representing, or capturing, the student's perception. This RAPS instrument could possibly be modified to become more applicable to the interactive multimedia environment. A key aspect of the RAPS instrument theoretical framework is summarized:

"The Research Assessment Package for Schools (RAPS), that includes strategies and instruments for measuring four major components of the school-site reform framework:

1. Key indicators of student performance and adjustment
2. The supports and opportunities experienced by students in schools
3. The supports and opportunities experienced by adults in schools (i.e. teachers, administrators, and other staff members)
4. The implementation of the seven critical features for school-site reform."

(IRRE, 1998)

Validation of the RAPS instrument was observed. Some 2,429 subjects, for a sample size n = 2,429, were observed. The instrument was administered in three middle schools within in the same urban school district and one middle school from an adjacent suburban school district, across multiple years (IRRE, 1998). Students from grades 6-8 and ages 10-15 participated. Other population demographics included, for Ethnicity: 44% African-American, 39% Euro-American, 16% Hispanic. Gender was fairly equally represented: 49% male and 51% female. To address the credibility of the RAPS instrument, this instrument research has also been published in numerous refereed and peer-reviewed journals.

So, within the RAPS instrument there are three main Domains or topic areas. In terms of reliability, these three major instrument Domains: Engagement, Beliefs About Self, and Experiences of Interpersonal Support, garnered reliability ratings (*alphas*) of 0.77, 0.87, and 0.88 respectively, where reliability ratings with alphas of 0.70 or higher are usually considered desirable. Considering the credibility of the RAPS instrument, should provide a solid foundation for a interactive multimedia applicable instrument.

- Educational System Standards and Metrics

Interactive multimedia Human Engagement is something that is of concern for game designers and educational/training systems administrators alike. This over-arching goal can be viewed as an important indicator of interactive multimedia efficacy and impact. Yet, within this goal of effectiveness, lies great complexity. This research looks to address this issue of complexity by defining key elements of Human Engagement in the interactive multimedia application area.

Once defined, standards may be created to help govern, evaluate, and delineate interactive multimedia technology effectiveness. Examples of educational standards are:

1. National Research Council's: National Science Education Standards
2. National Council of Teachers of Mathematics: NCTM List of Standards
3. Biological Science Curriculum Study (BSCS): Science Education Standards
4. National Council of Teachers of English (NCTE): NCTE List of Standards
5. Elementary and Secondary Education Act (ESEA): US National Education
6. No Child Left Behind (NCLB): U.S. National Education
7. State Educational Standards: Florida Sunshine State Standards (SSS)

Standards in education came as a result in efforts to improve the national educational state. Wenglinsky outlines the Standards movement spurred by the 1983 report entitled, "A Nation at Risk", produced by the U.S. Department of Education (Wenglinsky, 2005). Ironically, the early 1980's became known for an increase in quality and improvement-based initiatives in product manufacturing and services; education was the next logical area of interest. The aforementioned listed examples show that a standards-based approach to education can prove advantageous in the arena of interactive multimedia. Game designers are able to incorporate standard-backed content into game application design, yet the actual integration of game design and content is still rather unorthodox and non-standard across game applications. The need for a Human Engagement standard in interactive multimedia exists. Educational standards, especially in the area of accountability for administrators and teachers, are a major topic of No Child Left Behind

(NCLB) legislation (ED, 2007). The response to increase student academic achievement hinges on the establishment of educational standards and metrics.

Chapter 2 Summary

1. Eight major fields of study reviewed for their relevant contribution to the interactive multimedia used to train body of knowledge: Computer Sciences, Computer-based Learning, Mathematical Modeling, Psychology and Human Cognitive Sciences, Social Sciences, Industrial and Systems Engineering, Human Resource Management, and Educational & Training Systems.
2. Engagement definitions, relevant topic areas, and key personnel/institutions were created and identified for each field of study.
3. Computer Science: Engagement is viewed from a hardware/software design and human interface & usability perspective. Video and computer games have been in existence for nearly 50 years. The MMORPG game type will be reviewed extensively within this research since it contains common characteristics found in the educational classroom environment. Customized participant experiences are possible. Commercial designers incorporate socio-cultural and emotionally stimulating aspects to engage players, while educational gaming tends to minimize these aspects.
4. Computer Based Learning: Is defined as the use of computers or electronic computing devices which are the center of the educational and training experience. The Educational Technology Movement was defined by legislation in 1994. The movement addressed the

Professional Development of Teachers, Hardware Access, Connectivity, and Digital Content. Online and distance learning provide many with access to education regardless of the geographic location. The sense of presence, realism, and fidelity in a virtual environment are important to a learner's experience.

5. Mathematical Modeling: Regression analysis, which utilizes statistics, is one of the most prevalent methods utilized to build mathematical models. Also, Multicollinearity can have serious effects on the estimates of the model parameters and on the general applicability of the final regression model. Other cognitive models reviewed in the literature include Counterfactual, Fitt's Law, Classical Test Theory, Attribute Hierarchy Method, EPIC, Soar, ACT-R, GOMS, and Item Response Theory.
6. Analytic Hierarchy Process coupled with Fuzzy Set Theory provides an alternative to regression modeling.
7. Psychology and Human Cognitive Sciences: The literature has been dominated by cognitive approaches in interactive multimedia usage. Psychometric scaling is a method quite commonly used to quantify activities such as thinking, memorizing, recalling, and understanding; yet it is limited. Physiological response measurement methods include: Galvanic Skin Response, Electroencephalography, Eye Movement Tracking, Heart Rate Monitoring, and Respiration. A founded instructional design methodology must exist in order to ensure learning. The CRESST model provides the cognitive framework for this research.
8. Social Sciences: Engagement in the social context addresses the interactive multimedia environment as an extension of the real world (society). Research theory states that an

individual's cognitive level may be framed by their social context. Social interaction in gaming, especially the MMORPG, is a very prevalent and pertinent aspect of interactive multimedia. Also, studies show that video games may increase arousal but not hostility, this is an important aspect in society.

9. Industrial and Systems Engineering: Industrial and Systems Engineering addresses engagement from a more integrated approach by incorporating multiple aspects of engagement into a single coherent definition. Advances in quality philosophy implementation within the manufacturing arena have been realized in other non-manufacturing areas such as healthcare systems, financial systems, and educational systems. Frederic Taylor's Scientific Management as published in 1911 still provides insight for work designers of the 21st century including the foundation of instructional design task analysis.
10. Human Resource Management: Motivation is a key factor that may impact the level of Human Engagement. In the presence of waning motivation or other impediments to learning, humans have developed methods that keep them focused and on task referred to as Volition. Also, there are various management styles that may be utilized in order to better address the needs of the learner such as, Theory X and Theory Y; address human characteristics which transcend cognition and behavior.
11. Educational and Training Systems: Traditionally engagement has been defined from the perspective of an identified level of learner behavior, emotion, cognition, participation, and perception of self. Various instruments have been created to monitor qualitative aspects of learning; the Research Assessment Package for Schools (RAPS) Instrument is

of particular interest in this research. Educational standards have become of major concern as observed within the last 25 years, since they are viewed as the critical impetus to ensure increased academic achievement.

The literature review, in summary, has addressed multiple areas of study that lend relevance to interactive multimedia research. Within each of these fields of study the key contributing personnel and institutions were highlighted. Relevant topic areas were then discussed in efforts to increase the reader's understanding of Human Engagement in interactive multimedia application areas. The information obtained from the literature review is the foundation of this research and will be further delineated throughout the following chapters.

CHAPTER THREE: METHODOLOGY

Defined Human Engagement

Human engagement is a main concern for an interactive multimedia creator or an educational and training systems administrator. The summarized proposed methodological approach to create the Human Engagement measure of interest consists of:

1. A Subject interacting with a Interactive Multimedia Application stimulus
2. Collecting Observed Physiological Response Data
3. Collecting Observed Human/Perception Cognitive Demands Data
4. Merging the Physiological Response Data and Human/Perception Cognitive Demands Data via Fuzzy Set Theory based model (Engagement Defined)
5. Validating the model

These five steps are the core of the methodology that will be further detailed within this chapter.

The Interactive multimedia Application Stimulus

Experimental subjects will interface a commercially available MMORPG, scenario-based game in a multi-player (squad-based) computer game format. A local area network (LAN) will be established to facilitate online multi-player interactions between Subjects. The following Task

Analysis delineates frequent high-level tasks and behaviors in which subjects will enact when interfacing the game application:

Game-play Instructions (Task Analysis Example)

1. Task Identified: Subject obtains mission instructions within game application
2. Skills Requirement: Subject will visually interface with game instructions and listen to narrative.
3. Knowledge Requirement: Subject must be able to read at or above a 4^{th} grade level. Also the subject must comprehend and be motivated to act independently.
4. Ability Requirement: Subjects will be enabled to accomplish task by being provided 1 hour of game-play. Also, the computer workstation contains all tools required for successful fulfillment of tasks.
5. Difficulty: Task difficulty is relatively medium be it that instructions must be understood and executed independently of other participants. Training and tutorials are provided.
6. Criticality: Task is extremely critical. Proficiency determines mastery of high level goal and mission.
7. Consequences of Not Accomplishing the Task: Failure in task will result in failure of training session
8. The Frequency of Occurrence of the Task: How often does the task occur? Task occurs at outset of new mission/objective (One formal narrative and continuous access to displayed text in-game instructions via menus)

9. The Measures of Performance for the Task. How is task success defined and to what degree? : Mission Success or Failure obtained within the allotted time of 1 hour.

Game-play Action (Task Analysis Example)

1. Task Identified: Subject navigates around Virtual game environment
2. Skills Requirement: Subject will use (press) respective keys to navigate in the game environment and operate mouse.
3. Knowledge Requirement: Subject must know and understand the function of the keyboard and mouse as input devices (user perspective). Prior use of computers is required.
4. Ability Requirement: Navigation instruction will be provided during training session and available in look-up menus during game-play.
5. Difficulty: Task is somewhat difficult since both physical and cognitive effort must be synchronized in order to be successful.
6. Criticality: Task is extremely critical. Subject must know how to navigate.
7. Consequences of Not Accomplishing the Task: Task failure will result in training session failure.
8. The Frequency of Occurrence of the Task: How often does the task occur? Task occurs continuously.
9. The Measures of Performance for the Task. How is task success defined and to what degree? Task success is indicated by adequate use of input devices and visual feedback

from gaming application. For example, subject avoids potential negative situations and capitalizes on positive opportunities within the virtual game environment.

Physiological Response and Human Perception Cognitive Demands Data

Both quantitative and qualitative data will be used as the sources of collected data input to generate the Human Engagement fuzzy model which will be further discussed in detail, in the following chapters. The reasoning behind the combining of these two different data types is hinged on the fact that pertinent information as pertaining to the "response", in this case, human engagement, may be derived using both physiological response data and human perception data. The proposed framework which merges these different sources of data into a comprehensive quantifiable model will be developed and delineated within this body of work.

Quantitative Data (Physiological Responses)

As the output of the fuzzy mathematical model, the following physiological responses will be identified as prominent factors that impact or may be interpreted to indicate human engagement:

1. Human Respiration (CO_2 Concentration)
    a. As humans respire, the biological process of respiration occurs in which O_2 (Oxygen) is extracted within the lungs, and CO_2 (Carbon Dioxide) is exhaled into the air. A physical sample space of approximately one cubic meter for CO_2

concentration analysis can provide information about human physiological/psychological state change. The mean percent change in CO_2 concentration levels from subject baseline, may be used.

2. Human Eye Movement
    a. A remote eye tracking device may be utilized to track eye movements namely saccades (shifts in ocular fixations from one object or area to another). Typically saccades range in amplitude from 1 to 20 deg, corresponding to duration of 30 to 70 msec, and peak velocities of 70 to 600 deg/sec, respectively (Bahill and Stark, 1979). The mean percent change in number of saccades per time unit, from subject baseline (derived from a reading activity), may be used.
3. Human Heart Rate (Blood Volume Pulse/Blood Oxygen Saturation/Pulse Oximetry)
    a. Description:

    After further analysis and expert input, it was determined that of the identified aforementioned physiological response factors, Human Heart Rate, or BVP, would be the best factor to monitor. Reason being is that factors such as Human Eye Movement are extremely complicated in tracking and the current state of the technology is rather nascent; not acquiring consistent reliable measurements may be a potential result during experimental runs. Also, another issue, respiration, or changes in respiration may exist however utilizing pulse oximetry provides relative information about general tissue oxygenation which is of importance.

> In general, BVP, Blood Volume Pulse sensors or photoplethysmographs (PPG), work by emitting infra-red light towards the subject's skin. Then measurements of the amount of reflected infra-red light are taken. This amount of reflected infra-red will vary with the amount of blood present at the skin's surface since blood reflects red light and absorbs other color light. At each heart beat (pulse), there is more blood in the skin. Between pulses, the amount of blood decreases and more red light is absorbed. The mean percent change in BVP from subject baseline, will be used. Also, blood oxygen, or hemoglobin oxygen saturation (SpO_2) may be monitored and utilized.

The next paragraph will delineate the various methods for determining BVP and blood oxygen saturation.

The measurement of blood oxygen saturation levels is a more reliable method when compared to methods such as remote eye tracking, Electroencephalography (EEG), Galvanic Skin Response (GSR), and Skin Conductance Response (SCR), when attempting to measure arousal and cognitive activity. A considerable amount of noise can exist when measuring the electrical activity of the body. Skin, muscles, and cells exhibit electrical activity. Cerebral oxygenation is extremely important and is a direct indicator of brain neural activation. An increased level of neural activity results in an increased demand for oxygen. It is therefore logical to conclude that localized blood oxygen level assessment may be quite useful in psychosocial research in interactive multimedia.

The following narrative is not exhaustive, but mentions examples of the core principles used in determining blood oxygenation levels non-invasively: photo/optical, magnetic, and nuclear techniques.

Method: Pulse Oximetry

Pulse oximetry utilizes knowledge of how oxygenated and deoxygenated hemoglobin behave in the presence of electromagnetic radiation, such as Infra-red light. A pulse oximeter emits light via LED's, at two varying wavelengths of 600's nm and 900's nm through the sample and some light reaches a photodiode which detects light. The absorption property of hemoglobin (and oxygenated hemoglobin) varies at different wavelengths of light. The resultant measures at both wavelengths are used to calculate a ratio which in turn indicates the percent oxygen saturation. Also, Blood Volume Pulse may be calculated.

<u>Advantages</u>

- Good reasonable estimated measurements
- Quick readings
- Inexpensive
- High Portability
- Can calculate Blood Volume Pulse and Blood Oxygen Saturation

- Allows high subject mobility during assessment

Disadvantages

- Limited to thin body parts small feet (newborns), fingertips, and earlobes
- Finger or earlobe blood oxygenation levels may noticeably lag changes in brain oxygen levels according to research (Jensen, Amory, & Li, 1990)
- Utilizes common point measurement techniques
- Subject to circulation quality and extremity site state

Method: Functional Magnetic Resonance Imaging (fMRI)

fMRI is a magnetic resonance technique that differs from traditional MRI, in that changes in brain neural activity can be monitored. As brain activity increases, oxygen demand increases. Traditional MRI's utilize an extremely strong magnetic field which impacts the magnetic properties of abundant types of atoms in the body, usually hydrogen. The resultant magnetic signal is then detected by the scanner thus providing a detailed image of the area of interest. Hemodynamic response, described as when blood releases oxygen to active neurons faster than to inactive neurons. Thus blood flow in the brain is dynamic and is dependent on the demand of oxygen required during neural activity. The difference in the magnetic properties of oxyhemoglobin and deoxyhemoglobin can be detected by the scanner.

Advantages

- Great precision and image resolution
- Localized brain blood oxygenation assessment possible
- Can determine organ oxygenation
- Does not expose subject to significant levels of radiation

Disadvantages

- Subject has extremely limited mobility during scans
- Expensive equipment

Method: Single Photon Emission Computed Tomography (SPECT) Imaging

This method utilizes nuclear medicine technology mainly a gamma camera captures 2-D photos of tissues saturated with gamma emitting tracer ^{99m}Tc-HMPAO (Technetium-99m-hexamethylpropylene amine oxime). The multiple 2-D picture slices are compiled by a computer into a 3-D dataset. Blood flow can be monitored as tracer is absorbed by various parts of the brain due to its attachment to hemoglobin.

Advantages

- Localized brain blood oxygenation assessment possible through blood flow analysis
- Can determine organ oxygenation
- Great precision when preparation is adequate

Disadvantages

- Expensive equipment
- Subject's exposure to Gamma radiation is not the best
- Tracer must be ingested or injected
- Limited subject mobility

Method: Reflectance/Optical Spectroscopy

Reflectance spectroscopy can be used to analyze localized blood oxygen levels in tissues. Non-invasive reflectance spectroscopy utilizes a hyper-spectral imaging system. This method differs from other methods such as pulse oximetry, since local measurements of blood oxygen level of tissue as opposed to common point measurements can be made. Various optical properties of blood and tissue, such as the degree of the scattering/reflectance of light or absorption make the technique possible. EM radiation, Near Infrared and Infrared light, is

emitted towards tissue or blood and detected by a photo detection sensor. Scattering properties of various tissues indicate distinct characteristics.

Generated algorithms which are designed to calculate the blood oxygen saturation from narrow band reflectance images at 760 and 800 nm are used. Oxyhemoglobin and deoxyhemoglobin exhibit distinct optical properties. Research provides evidence that this method can be used to calculate blood oxygen saturation levels (Martinez, 2002).

Advantages

- Localized tissue blood oxygenation assessment possible
- Good precision
- Can determine organ oxygenation
- Affordable equipment costs

Disadvantages

- Algorithms may require updating

Method: Fiber Optic Probes

Fiber optic probe methods are very similar to other photo based methods that utilize Light emitting diodes LED's at specified wavelengths. The LED's are connected to the fiber optic path. The difference in the fiber optic probe method is that "the source and detector fibers are on the same side of the tissue sample" (Co, Hess, & Shelton, 2006). The tissue sample does not have to be between the source photo emitters and the detectors, as in pulse oximetry. Scattered light intensities are collected rather than light transmission.

Advantages

- Affordable equipment costs
- Allows high subject mobility during assessment

Disadvantages

- Utilizes common point measurements
- Deep tissue limitations can be overcome with high power output

These three identified physiological response factors can provide input data that may be used to define the Human Engagement fuzzy model; however, Heart Rate will be the only factor investigated within this research. Once the data has been obtained, SME's will then analyze the

output range for the heart rate physiological response in terms of mean percent change from established subject baseline measurements.

Method: Functional Near Infrared (fNIR) Imaging "Optical Brain Imaging"

Functional Near Infrared Resonance Imaging (fNIR) is another physiological measurement technique that examines the behavior of blood in tissues. It is more specifically used in non-invasive brain exploration. fNIR indirectly measures brain activity much like that of fMRI, by observing blood flow and oxygenation levels in the brain.

Advantages

- fNIR use mitigates the concerns of magnetic related interference and issues found in fMRI
- Non-invasive
- Smaller apparatus

Disadvantages

- Moderately expensive, yet less expensive than other methods

Qualitative Data (Human/Perception Cognitive Demands Data)

The questions contained in the embedded survey instrument are derived from:

1. Augmented Baker & Mayer's CRESST model of Learning (Cognitive Demands)
2. Research Assessment Package for Schools (RAPS-SM) Instrument (1998)

The RAPS instrument contains domains and sub-domains which are correlated to the Cognitive Demands of the Baker & Mayer's CRESST model. The instrument will be administered as a part of the actual game-play. How truly the statement/question represents the subject's perception or belief, is recorded.

Table 7 Human Perception & Cognitive Demands Instrument

	Statement/Question	CRESST (Cognitive Demand)	RAPS-SM (Domain/Sub)	Other
1	The mission is **hard.**	Problem Solving (j_3)	Engagement (Ongoing)	-
2	The mission is easy.	Problem Solving (j_3)	Engagement (Ongoing)	-
3	You are **not** prepared for the mission.	Content Understanding (j_1)	Engagement (Ongoing)	-
4	You are prepared for the mission.	Content Understanding (j_1)	Engagement (Ongoing)	-
5	You can**not** complete the mission if you work hard.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
6	You can complete the mission if you work hard.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
7	You can**not** complete the mission because the team will **not** help you.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
8	You can complete the mission because the team will help you.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-

	Statement/Question	CRESST (Cognitive Demand)	RAPS-SM (Domain/Sub)	Other
9	You feel **bad** when you think about how you are performing.	Self-Regulation (k_3)	Beliefs About Self (Relatedness)	-
10	You feel good when you think about how you are performing.	Self-Regulation (k_3)	Beliefs About Self (Relatedness)	-
11	You feel **alone** in the game.	Collaboration or Teamwork (j_2)	Beliefs About Self (Relatedness)	-
12	You feel you are part of the team.	Collaboration or Teamwork (j_2)	Beliefs About Self (Relatedness)	-
13	The team **ignores** you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
14	The team listens to you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
15	The squad leader does **not** have clear expectations for you on the team.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
16	The squad leader has clear expectations for you on the team.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
17	The squad leader does **not** like the other team members more than you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
18	The squad leader likes the other team members more than you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
19	Team members do **not** tell you when they need help.	Communication (j_5)	Interpersonal Support	-
20	Team members tell you when they need help.	Communication (j_5)	Interpersonal Support	-
21	It is **hard** to talk to the team about the mission.	Communication (j_5)	Interpersonal Support	-
22	It is easy to talk the team about the mission.	Communication (j_5)	Interpersonal Support	-
23	You do **not** want to continue the mission because it is boring.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
24	You want to continue the mission because it is interesting.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
25	**Not** knowing how well you are doing makes you want to quit.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
26	Knowing how well you are doing keeps you playing.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
27	The graphics in the game are **not** good.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
28	The graphics in the game are good.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
29	You do **not** feel like you are part of the game.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
30	You feel like you are part of the game.	-	Engagement (Challenge)	Realism and Fidelity (j_7)

	Statement/Question	CRESST (Cognitive Demand)	RAPS-SM (Domain/Sub)	Other
31	You do **not** feel it is your responsibility to complete the mission.	-	Beliefs About Self (Competence)	User Control/ Entitlement (k_2)
32	You feel it is your responsibility to complete the mission.	-	Beliefs About Self (Competence)	User Control/ Entitlement (k_2)
33	You do **not** feel you have total control over the mission.	-	Beliefs About Self (Competence)	User Control/ Entitlement (k_2)
34	You feel you have total control over the mission.	-	Beliefs About Self (Competence)	User Control/ Entitlement (k_2)
35	You do **not** feel excited.	-	Beliefs About Self (Relatedness)	Affective/ Emotional State (j_4)
36	You feel excited.	-	Beliefs About Self (Relatedness)	Affective/ Emotional State (j_4)
37	You do **not** like the game.	-	Beliefs About Self (Relatedness)	Affective/ Emotional State (j_4)
38	You like the game.	-	Beliefs About Self (Relatedness)	Affective/ Emotional State (j_4)

Since, the Human Perception & Cognitive Demands Instrument is not assumed to be absolutely perfect, because human participant responses are not absolutely repeatable and accurate one-hundred percent of the time, sampling error exists. Ideally the instrument should be administered, i.e. subjects will play the same game, to the same participants multiple times to mitigate various types of sampling error. Consensus on the allowable level of model variability, error, is the responsibility of system experts and has a bearing on the confidence level of the formulated Fuzzy Model.

Merging the Physiological Response Data and Human/Perception Cognitive Demands Data (Engagement Defined)

As stated in the previous chapter, the focus of this research will delineate the level of Human Engagement, within the interactive multimedia application area of interest. The hypothesis that Human Engagement along with other factors, affects human overall human experience, is pertinent. In order to produce concise research within limitations, the human engagement factor will be the only factor examined in detail. In this research human engagement is comprised of physiological response data and human perception/cognitive demands data as seen in the next figure.

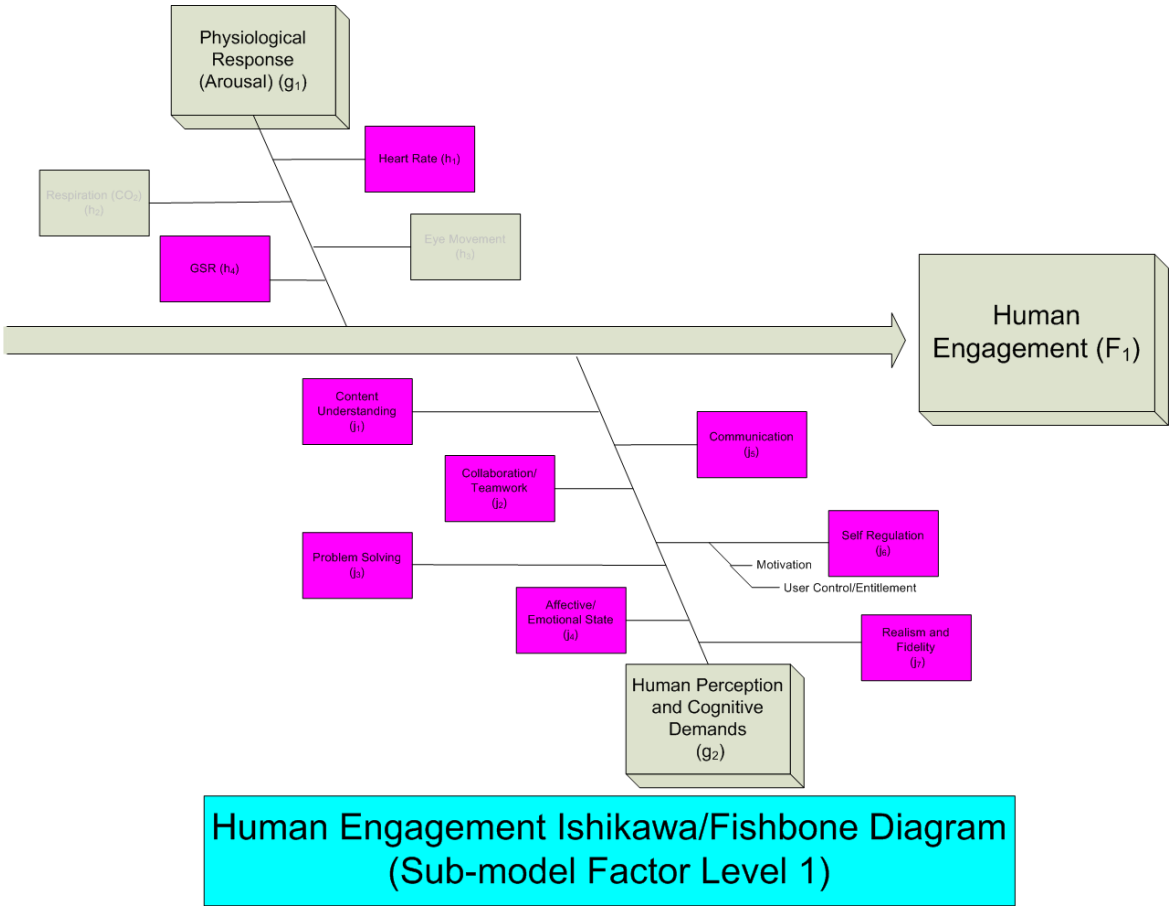


Figure 6 Human Engagement Sub-model Factor Level Hypothesis

Factor and sub-factor coefficient weightings will be assigned by a process known as Analytic Hierarchy Process (AHP), which differs from the Regression Analysis case, where regression coefficients (weightings) would be generated by a least squares approach.

In AHP either Subject Matter Experts or generated data may be used to determine the coefficient weightings based on the ranking of pair-wise comparisons of factors and sub-factors by assessing their relative impact on the goal of Human Engagement. The data derived from AHP can then be used to determine the coefficient weights of the Fuzzy Model discussed later in Chapter 4, more specifically the weight of the coefficient for the Human Engagement Factor. Analytic Hierarchy Process (AHP) will be further detailed in the following Chapter 4 of this body of work.

Once the factor and sub-factor coefficient weightings have been derived, the Physiological response data (which is already quantified) will be merged with the Human Perception and Cognitive Demands qualitative data. As referenced previously, the degree of trueness (DOT) the subject indicates for each question type within the Human Perception and Cognitive Demands Instrument (HPCDI) is the foundation of the Fuzzy Model. This qualitative data can then be quantified. Each question corresponds to a particular cognitive demand and sub-factor which in-turn can be used to indicate the level of existence for the respective cognitive demand or sub-factor. Fuzzy Set Theory can then be used to quantify the responses. Fuzzy linguistic level assignment, which is a translation of the linguistic terms of perceived trueness, transforms the subjects' responses into quantitative information. The Fuzzy linguistic level assignments are

made by the researcher from the RAPS-SM Instrument and determined that 5 linguistic levels of trueness would suffice to model the levels:

1. Absolutely True
2. Very True
3. Sort of True
4. Not Very True
5. Not At All True

Usually 3-5 defined linguistic levels are used because as the number of levels increases, the complexity increases and the potential for related sampling and data collection error increases as well. The use of the Fuzzy approach in scoring classification helps to accurately and consistently rank linguistic values. Humans tend to rank and describe events, items, and their perception based on a continuum, a range, rather than as a discrete exact statement. Linguistic comparisons words and phrases such as; “Like”, “Sort of”, “Not Very”, and other adverbs, identify the existence of uncertainty and the lack of absolute certainty, which humans encounter on a continual basis. The Fuzzy level assignment in this work will be referred to as “The Degree of Trueness” (DOT). Trained evaluation personnel SME’s will utilize the information in the Human Perception and Cognitive Demands Instrument (HPCDI) to assess the level of human engagement.

The DOT can best be described as, “a subject’s perception of his/her level of cognitive interaction within the gaming environment”. The Degree of Trueness is the foundational component of the analysis portion of the formulated Fuzzy Model.

Experimental Setup

The stimulus in this research is the actual Serious Game/Virtual Environment apparatus. This apparatus will consist of the following aspects of the testing environment:

1. Hardware
    a. Processing: Intel Pentium 4/AMD Equivalent (Minimum)
    b. RAM Memory: 1 Gb (Minimum)
    c. Storage: 20+ Gb
    d. Audio: 2 Channel Stereo
2. Software (Experimental Stimulus):
    a. Operating System: Microsoft Windows XP
    b. Stimulus: 1st Person MMORPG (Squad-based)
    c. Software (Experimental Stimulus)
3. Output Device(s):
    a. Video: Monitor
    b. Audio: Headphones (Integrated Headset)
4. Input Device(s):
    a. Microphone (Integrated Headset)

b. Standard Keyboard

c. Standard Mouse

5. Experimental Data Capture Devices (Sensors) (Bold-faced indicates sensors and equipment to be used)

6. Heart Rate Monitor (Exercise Heart Rate Monitor)

    a. Galvanic Skin Response (GSR)

    b. Human Perception and Cognitive Demands Analysis Instrument (Embedded in game-play)

    c. Video Capture device

        i. Wireless/Wired Video Cameras/Capture Devices

        ii. Video storage device

Notes: Due to the nature of human perception qualitative data, minimally invasive approaches should be used to mitigate the potential human subject's impact due to experimental setup and biosensors usage. For this reason, sensors which may noticeably cause excessive abnormal comfort levels, such as Galvanic Skin Response (GSR) and Electroencephalography (EEG) were avoided. Sensors which do not create uncomfortable direct contact with the subject's body and can easily be hidden were intentionally chosen for this research.

7. Experimental Environment:

    a. Subjects are physically isolated from other participants; contact is only established via the stimulus virtual game-world.

    b. Experimental Stimulus Exposure Time: 1 hr. (with included preparation time)

        i. Traditional Instructional Video Method: 15 min.

ii. Level 1 (1st Person): 15 min.

iii. Level 2 (Multi-player): 15 min.

iv. Level 3 (3rd Person): 15 min.

c. Subject Orientation/Position: Seated upright at workstation with feet on floor

d. Ambient Temperature Range: $70^{o} – 75^{o}$ F

e. Ambient Sound Level: Less than stimulus decibel level (the stimulus should be the most significant source of sound)

f. Ambient Lighting Level: Darkened Room

g. Workstation design:

i. (1) Computer

ii. (1) Integrated Gamer Headset

iii. (1) Heart Rate Monitor

iv. (2) Video Camera/Capture Devices

v. (1) Chair

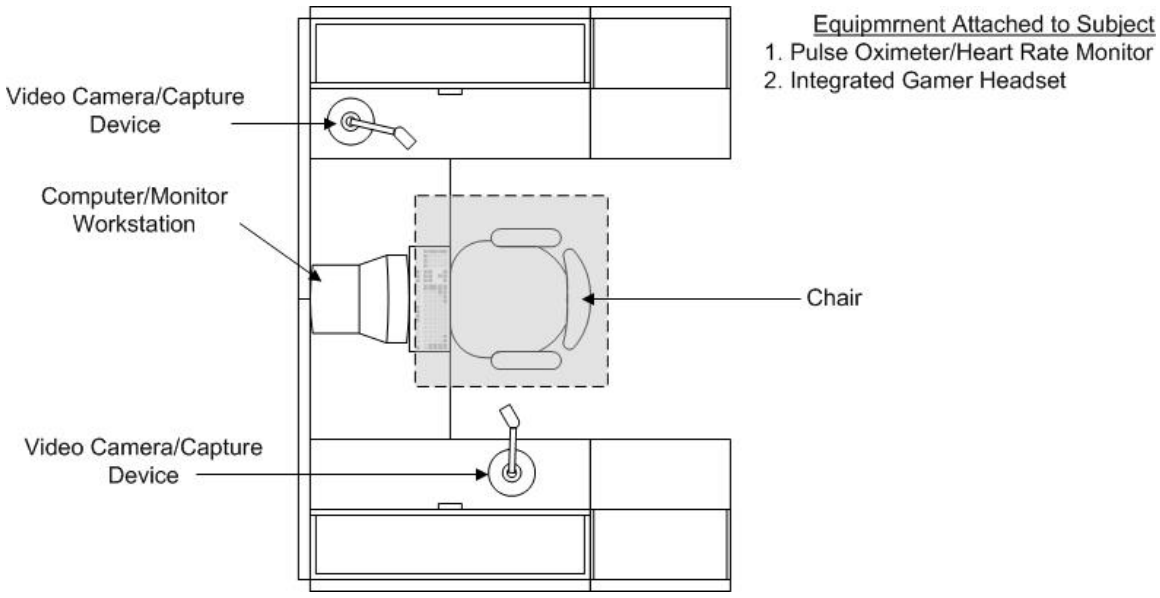


Figure 7 Workstation Design Layout

Experimental Stimulus Selection

The genre of games that will be utilized as the experimental stimulus is the Squad-based First Person Shooter, consisting of two players on a single squad. This type of game can be considered a true multiplayer application (in upwards of 6 squad members or more may participate simultaneously) which is reminiscent of the Massive Multiplayer Online Role-Playing (MMORPG) where hundreds to thousands of players may participate simultaneously. The reason for not using the expansive MMORPG, initially, is that when in a vast multiplayer environment sources of variability are more prevalent and may be manifested in the form of: extraneous player disruptions, MMORPG environment access issues (server down-time), and extraneous tasks. A true controlled "MMORPG sandbox" would be ideal. It is very possible that squads or

teams may be coordinated within a MMORPG also. More control is needed, initially, to ensure that usable and applicable experimental results can be ascertained. The next step would then be to use a full-fledged MMORPG gaming environment as the experimental stimulus.

Utilizing three different game applications would provide useful information about across experimental stimulus variation. There is hypothetical potential that subjects will interface and perform differently for various similar type gaming applications. For instance, the following gaming applications were selected based on their popularity or generated revenues/sales (when data was available). It may be noted that the user ratings were used to determine the popularity level of the game. All game data is provided by GameSpot (2008), a CNET Networks Entertainment effort.

Level 1 PC Game: Call of Duty 2 (COD2)

- Producer/Publisher: Activision
- Popularity Level: High
- User Rankings: 16th (2006) Top 20 PC Games (9.1/10)
- ESRB Rating: T
- Game Type: Historic First Person Shooter (FPS)
- Player Role: Soldier of WWII

- Description: “As in the first game, Call of Duty 2's campaign will put you in the shoes of a few different soldiers fighting for different Allied factions. Multiplayer Call of Duty 2 picks up right where the original left off, offering standard death-match, team death-match, and capture-the-flag modes, along with the search-and-destroy mode from the original game, where one team has to plant a bomb and destroy one of two objectives while the other team defends. A mode called "headquarters" is also available, and it's probably the most enjoyable mode of the five available in COD2. In this mode, two different areas on a map are designated as capture points for either of the two teams. To score points, a team must control and set up a headquarters on one of the two areas. Once that's set up, points begin increasing for the controlling team. The other team must attempt to overrun the position to try to stop the points from ticking up.”

Level 2 PC Game Stimuli: Tom Clancy’s Rainbow Six 3 Raven Shield (RB6)

- Producer/Publisher: UBISOFT
- Popularity Level: Medium
- User Rankings: (8.7/10)
- ESRB Rating: M
- Game Type: Tactical Shooter
- Player Role: Elite Tactical Anti-terror Squad Leader

- Description: “Since its debut in 1998, the Rainbow Six series has been an outstanding example of how exciting sophisticated tactical shooters can be, thanks to its challenging "one-shot kill" game-play and complex mission planning. And even though the tactical shooter subgenre has become even better thanks to great games like SWAT 3 and Operation Flashpoint, fans still eagerly look to each new Rainbow Six installment to see what the series has in store next. While Rainbow Six 3: Raven Shield does little to push the tactical shooter genre forward, it's still an exciting entry in the series. Raven Shield lets you outfit your operatives with the latest gear and firearms. Just like the previous Rainbow Six games, Raven Shield lets you lead a group of elite international counter-terrorists known as Rainbow. These guys are equipped with high-tech gear and high-powered firearms and are itching for an opportunity to shout, "Tango down!" In Raven Shield, you'll help the Rainbow operatives on a mission with a rather forgettable plot that involves a James Bond-style madman and Nazi loot from World War II. In fact, as you play the rather short single-player campaign, you'll find that storytelling isn't one of Raven Shield's strong suits. You'll receive clear text and audio mission briefings and see a few well-directed but brief cut-scenes, but these sequences don't quite create a strong sense of drama or immersion. Rather, the storytelling feels like merely a flimsy framework to hang the tactical combat on.”

Level 3 Tom Clancy’s Splinter Cell Chaos Theory (SPL)

- Producer/Publisher: UBISOFT
- Popularity Level: High

- User Rankings: (9.1/10)
- ESRB Rating: M
- Game Type: Sci-Fi Shooter
- Player Role: Single Spy
- Description: “The third iteration of the Tom Clancy's Splinter Cell stealth action franchise features the continuing adventures of Sam Fisher, a top secret agent who's sent in to accomplish the US government's dirty work when political situations go sour. It's also got a brand-new two-player cooperative mode in addition to an updated version of the innovative spies-versus-mercenaries competitive multiplayer mode introduced in the second Splinter Cell game. So there's a lot to it, and there's definitely a lot to like about it, especially for Splinter Cell fans who felt a little too restricted while playing as Fisher in the previous games. With that said, Chaos Theory sometimes has a designed-by-committee feel due to its many disparate parts, and despite the game's grittier new theme and its new "Mature" rating, it's going to offer a familiar experience to Splinter Cell veterans. But even if some of the changes are marginal, this is still the most entertaining, most well-rounded game in the series yet.”

Experimental Design Groups and Runs

Experimental Design Groups and Runs Description

This research is not on game design, in which a control group may be required. For example, if the research objective was to determine which type of mode of instruction is most effective, then the research would probably warrant the use of some type of control group. Though in this research, baseline measures are established as the subject is exposed to a traditional mode of instruction, i.e. reading written text and watching an instructional video (non-interactive), then the subject is immediately exposed to the game stimulus. Please note that the traditional mode of instruction is used as a method to establish pre-stimulus levels of engagement. The potential differences and changes from baseline are then observed. This research is a Time-Series type of experimental design. The Time Series design can be augmented with multiple levels of the experimental stimulus, just as long as there are no changes in subject group assignment. It may be beneficial to use multiple stimuli (game applications) with varying levels of intensity, or market game popularity/user rating.

Also, other types of research experimental designs researched were:

1. Posttest-Only Control Group: The Posttest-Only Control Group involves the random assignment of subjects to groups, hence mitigates the need to review pre-stimulus performance measures
2. Nonequivalent Control Group: Nonequivalent Control Group designs do not consist of randomly assigned subjects to the experimental or control group, steps should be taken to

identify the equality of the experimental and control group prior to stimulus exposure (pre-test or established common sample characteristics that are related to performance). When there are no identifiable differences across groups before exposure to stimulus, post-stimulus results will indicate the impact of the stimulus.

3. Parallel Test: Parallel testing helps to mitigate the "test effect", when a subject performs significantly different on the same tests that were presented in a pre/post assessment design. A parallel test is not the same exact test but addresses the same learning objectives. This may be required since a pre-test may actually help or prepare the subject for the identical test, administered as a post-test.

(Davidove, 2002)

Validating the Model

Model validation is essential in model development. An invalid model will produce invalid results. Within the validation phase a controlled test environment will be utilized to minimize unwarranted system impact. Validation extends beyond the within experiments reliability to that of how well the model will represent the level of Human Engagement. Types of methods and model validation techniques include:

1. The use of model consistency measures (Cronbach's α) to validate model adequacy
2. The use of system expert knowledge to validate model outputs

3. The use of comparisons analysis between established expected systems objectives and the resultant model outputs
4. Comparisons in results between established methods (such as Likert and Ordinal scaling methods) and Fuzzy Mathematical Analysis.
5. The use of quantitative analysis of variance techniques (ANOVA)

Once evaluated and deemed ready, the findings may be utilized and implemented. Feedback is generated from the findings and improvement in design is initiated as detailed in the following sections.

Chapter 3 Summary

1. Human Engagement is a factor in the overall human experience. The methodological approach and Human Engagement application area of this research will focus on empirical observations of subjects interfacing with a interactive multimedia.
2. Physiological Response measurements in this research will include: Heart Rate and GSR
3. Physiological Response data will be merged with Human Perception Cognitive Demands data via the use of Fuzzy Mathematical modeling to produce a quantified output.
4. Instrument and model validation will also be conducted.

The methodology was created with the intention of providing the framework for standards and metrics creation in the interactive multimedia application areas. It is quite plausible that this

framework can be applied to not only interactive multimedia but also to entertainment multimedia and marketing.

The next chapter will delineate the details of the Fuzzy Mathematical Model and how factors that impact engagement are related.

CHAPTER FOUR: MODEL DEVELOPMENT

Fuzzy Set Theory versus Regression Analysis

In this Chapter 4, there will be a focus on the applied Fuzzy Mathematical Model theory. The detail comparisons of regression analysis versus Fuzzy Set Theory will be discussed; the next table is a summary of those similarities and differences.

Table 8 Regression vs. Fuzzy Modeling

Category	Regression Analysis	Fuzzy Modeling
Model Creation	1. Choice of Appropriate Model Form is Imperative. 2. Sample data should come from In-Control Process (Low Variability).	1. Model form is more general. 2. Model may or may not be derived from observed process data but by system experts.
Model Adequacy (Reliability)	1. Coefficient of Determination (R^2)	1. Cronbach's Alpha Coefficient of Reliability (α)
Sampling Error/Standard Error	1. SE calculated	1. SE calculated
Model Maintenance	1. Collect more observed data to update changes in the model.	1. Sequester SME's to agree on updates. 2. Also data may be collected.
Response Interpretation (Output)	1. Quantitative requires interpretation by deemed persons.	1. Quantitative more intuitive in nature due to Fuzzy Level Assignments by SME's.
Type of Collected Data (Input)	Quantitative/Qualitative	Quantitative/Qualitative/Hybrid
Qualitative Variables	Binary (0 or 1)	Multi-valued [0,1]
Model Usage	1. Not recommended for model usage (prediction) outside of the range of the collected data	1. Designed to be used in scenarios where data is lacking or process is vague
Factor Confounding	Confounding of Factors is a concern	Confounding is not a concern due to nature of model development

Regression Analysis

The reason to use Linear Regression is to create a model that represents an observed Real-World scenario. The process of creating a regression model begins with a single graphical line, referred to as the regression line, and is fit to the observed data points, usually which have been displayed using a scatter diagram. The most common method used for determining this single line that has the minimum summed error or deviation between the line and data points is referred to as the Least Squares Method. The Least Squares Method examines a series of data points in relation to the suggested regression line that results in the least squared amount of deviation between each point and the line, which is then converted to Sum Squared Error (SSE) by squaring the deviations to prevent negative signed error. This SSE, and other error measures, is indicators of model adequacy. However there are conditions in which error measures may indicate unreliable model adequacy. Multicollinearity, an example of a real-world scenario issue, is a concern which may obscure the true results of a model and skew its accuracy.

Regression Analysis is an extremely well known and widely accepted data analysis technique. Regression Analysis is limited to and by the range of the data used to derive the regression model. Model usage for conditions which reside outside of the range of the data used to derive the regression model should be avoided since potential model error cannot be accounted for. The following is the mathematical form of the regression equation.

Multiple Linear Regression Form

The Multiple Linear Regression form may be expressed as the following equation:

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \varepsilon$$

Where:

1. y = Dependent variable or response
2. (x_i) = Independent Variable
3. β_0 = y-intercept of the graphed line
4. β_1 = the amount of change of (y) for every one-unit change of (x_1) when (x_2) is held constant.
5. β_2 = the amount of change of (y) for every one-unit change of (x_2) when (x_1) is held constant.
6. ε = Random error component

(Myers & Montgomery 2002)

There are some important things that should be considered when using Regression Analysis. In using regression analysis, the system to be modeled should be in statistical control (meaning Low Variability & Steady-State Operations) and that the resultant statistical distribution of the observed data should be identified (Myers & Montgomery 2002). Also, other foundational assumptions should be met such as:

1. Regression Model Error is Normally Distributed with a Mean Value = 0
2. Regression Model Error is uncorrelated and Normally Distributed

3. Independence between factors should exist (i.e. correlation between factors should be minimal)
4. The sampling distribution of each estimated regressor should be normally distributed.

Also, in addition, other issues that may complicate or negatively impact the use of regression as stated by Shapiro (2006) include:

1. Inadequately sized (small data sets)
2. Vagueness in relationship between input and output variables

Qualitative Variables in Regression Analysis

The literature, overwhelming, supports the use of qualitative variables in Regression Analysis. However, the regression approach usually considers the qualitative variables to be binary in nature (Myers, & Montgomery 2002), (Shapiro, 2006), (Derrick, 1979). This is indeed a problem when the actual qualitative variables are not binary but are multi-valued, as in the case of this research. Fuzzy mathematical approaches state that variables reside within an interval between and including [0, 1].

Regression analysis literature directs users to apply the following methodology when incorporating qualitative variables:

1. Determine the number of qualitative variables (t) of interest, where the number of qualitative variables to be used in the model is t - 1.

2. Determine the level of qualitative variables
3. Use indicator variables (dummy variables) to determine when the variable effect is observed (1) and when it is not (0). One indicator variable may exist at a time (i.e. have a value of 1 while all others are 0)

The resultant effect is that when the indicator variable = 1, the intercept of the regression model is impacted. When indicator variable = 0, the other regression parameters are not affected.

Example

Assume a two factor linear regression form where: x_1 = quantitative variable (temperature) and x_2 = qualitative variable (2 machine types A and B):

$$y = \beta_0 + \beta_1 x_1 + \beta_2 x_2$$

$x_2 = 0$ if observation is from machine A

$x_2 = 1$ if observation if from machine B

Modeling multiple qualitative factors in regression requires that multiple variables be introduced in the design matrix since dummy variable levels are limited requiring creation of additional dummy variables. In essence, by simply adding more variables to a model would increase the chances for Multicollinearity. Also, the additional variables would require more residual degrees of freedom (df) (Derrick, 1979), in which df is sample dependent, in order to estimate the

regressor parameters and determine factor significance. Other issues that may occur when using dummy variables in regression analysis is that complete confounding of dummy variables may occur if there is not at least one observation for each qualitative variable (Hurst, 1970). If confounding occurs, it may become impossible to tell which qualitative variable is impacting the response and to what degree. As stated by Hurst, in another example, if we were interested in marital status and class rank of students and the following data was collected:

Table 9 Multicollinearity Example Data Table

Class Rank	**Fr**	**So**	**Jr**	**Sr**	**Gr**
Marital Status: Single	35	20	15	0	0
Marital Status: Married	0	0	0	15	10

The numbers in the table are counts, and then class rank is completely confounded with marital status. This type of scenario could easily happen in this research in which the "Problem Solving" fuzzy level membership may be 0 and the Realism and Fidelity fuzzy level membership may be greater than 0 in all observations (i.e. graphics and resolution may be great but the game lacks founded pedagogy), then there is a potential for these two qualitative variables in being completely confounded with each other within a regression model scenario.

The assumption in support of the usage of dummy variables in lieu of qualitative variables in regression is problematic for this type of human engagement modeling. When there are multiple

qualitative variables (factors), one factor at a time, only can contribute to the dependent variable (response), according to regression analysis theory. However in human engagement modeling it is highly possible that multiple qualitative factors exist simultaneously, thus impacting the response. Fuzzy modeling is able to cope with such conditions. The following section will address Fuzzy Set Theory versus the Classical Set theory.

Creation and Manipulation of Fuzzy Sets vs. Classical Sets

Within Mathematical Set Theory, Fuzzy Set Theory may be compared and contrasted with Classical Set Theory. The following discussion will delineate various aspects of both theories.

Mathematically Defined Classical Discrete Set Theory

S: Is the Universal Set

U: Is a subset of S

x: Is the element of interest

$U: x \rightarrow \{0,1\}$

For each element of S there exists an element of interest, and a value of membership where {0 = Not a member of the set U} or {1 = An absolute member of the set U}.

Classical Discrete Set Theory (Intersection of A and B)

$P(A \cap B) = P(A) * P(B)$

An event is a collection of simple events specifying the occurrence of an outcome of element x in an experiment. The probability of occurrence of the Intersection of event A and B in a Classical set is expressed as the product of event A and event B. Event A and B are assumed to be independent events (probabilities of occurrence) of some element x according to the Multiplicative Rule for Independent Events (Mendenhall, 1994).

For Example if:

$P(A) = 0.80$

$P(B) = 0.80$

$P(A \cap B) = 0.64$

Classical Discrete Set Theory (Union of A or B)

$P(A \cup B) = P(A) + P(B) - [P(A \cap B)]$

The probability of occurrence for the Union of event A and B in a Classical set is expressed as the sum of event the probabilities A and event B minus the probability of intersection of event A

and B. Event A and B are assumed to be independent events of some element x, according to the Additive Rule of Probability (Mendenhall, 1994).

For Example if:

P(A) =0 .80

P(B) =0 .80

P(AUB) =0 .80 + 0 .80 – (0.64) =0 .96

In the next discussion we will see how FST differs from the Classical Discrete approach and the impacts of these differences.

Mathematically Defined Fuzzy Set Theory

S: Is the Universal Set (Universe of Discourse)

F: Is a Fuzzy subset of S

x: Is the element of interest

F: $\mu(x)$

For each element of S exists an element of interest, and a value (μ) contained within the interval from [0,1]. This interval determines the degree of inclusion of x as a member of set of F. Another explanation of this FST concept is that the Fuzzy Relation/Membership Function μ_s: $x \rightarrow [0,1]$,

states that Universe of Discourse (S) exists and the element x is determined to exist within this Universe expressed as a value on the interval from 0 to 1.

Fuzzy Set Theory (Intersection of A and B)

$\mu_{(A \cap B)}$ = Min. of $\mu A(x)$ or $\mu B(x)$

Note: This is the Fuzzy equivalent of the classical probability of intersection. This "minimum" definition operator is not the only way to define the intersection of the fuzzy set but is used quite extensively throughout the literature (Smithson, 2006).

The degree of occurrence of two events A and B in a Fuzzy Set scenario is expressed as the minimum value of either the degree of occurrence of event A or event B.

For Example if:

$\mu(A) = 0.80$

$\mu(B) = 0.80$

$\mu_{(A \cap B)} = 0.80$

Fuzzy Set Theory (Union of A or B)

$\mu_{(A \cup B)}$ = Max. Of $\mu A(x)$ or $\mu B(x)$

Note: This is the Fuzzy equivalent of the classical probability of union. Also, as stated previously, the "maximum" definition operator is not the only way to define the intersection of the fuzzy set but is used quite extensively throughout the literature (Smithson, 2006).

The degree of occurrence of two events A and B in a Fuzzy Set scenario is expressed as the maximum value of either the degree of occurrence of event A or event B.

For Example if:

$\mu(A) = 0.80$

$\mu(B) = 0.80$

$\mu_{(AUB)} = 0.80$

In comparing the results of the previous examples in the Classical and Fuzzy Set cases we see the following results:

Table 10 Classical vs. Fuzzy

P(A) = 0.80 P(B) = 0.80	**Classical**	**Fuzzy**
$P(A \cap B)$	0.64	0.80
P(AUB)	0.96	0.80

In reference to set membership, for example, if we were to stratify the above results using a quartile approach setting the linguistic levels of qualitative grouping intervals results in the following values; the intervals would result in values seen in the following table.

Table 11 Fuzzy Linguistic Variable Table

Very Significant (4)	Significant (3)	Moderately Significant (2)	Not Significant (1)
1.00 - 0.75	0.74 - 0.50	0.49 - 0.25	0.24 - 0.00

It becomes apparent that the result of $P(A \cap B)$, the Intersection (A and B) of two (Very Significant) events is only considered Significant in the classical case but in the Fuzzy case, is still considered Very Significant. Also, as the number of events increases, no matter how high the values of each individual event, the probability of the Intersection of all events in the classical case, approaches zero. Hence in the qualitative sense, Fuzzy Set theory more readily preserves the qualitative or linguistic value.

In essence aggregation techniques mentioned previously include, most frequently, the Union and Intersection of Fuzzy Sets. By aggregating fuzzy variables we can assess the cumulative impact on a response. Also, another aggregation technique examines the arithmetic summation of linear combinations, as can be seen in question 2 under "Fuzzy Model Form" (McCauley-Bell & Crumpton-Young, 2005).

The following steps could be followed in order to create a Fuzzy Set:

1. Determine Fuzzy variables to measure
2. Collect Data
3. Establish Fuzzy Membership Function (If it has not been already created)
4. In the qualitative linguistic level scenario, defuzzify fuzzy variables with techniques mentioned in the following sections.

The next section will yield methods for the defuzzification of a fuzzy set.

Defuzzification of Fuzzy Set Variables

There are techniques that may be used to defuzzify a fuzzy set so that the resultant is a single numeric value. Methods include the Centroid Method, Center of Maxima Method, Mean of Maxima Method, Smallest of Maxima Method, and Largest of Maxima Method. McCauley-Bell and Crumpton-Young (2005) describes how the Centroid Method achieves a single numerical output by selecting a value within the range of the fuzzy variable, for which the area under the membership function graph is divided into two equal areas. Hence the resultant numeric value can be interpreted as the expected value for the fuzzy variable.

In essence, the Center of Maxima Method is the average value of the range of the fuzzy variables. However, the Mean of Maxima Method is very similar to the Center of Maxima

Method but is usually only referred to in the discrete case and addresses the average of all values in the crisp set.

The Smallest of Maxima Method centers on the process of selecting the smallest value, or minimum value, used in the Center of Maxima Method calculation. Finally, at the other extreme of the fuzzy variable range, is the maximum value, which is used as the defuzzified value in the Largest of Maxima Method.

The defuzzified resultant numeric value can then be used to represent the value of the fuzzy set.

Fuzzy Membership Functions

Geometric mapping functions also known as membership functions exist alongside the numeric aspect of Fuzzy Set Theory. In essence, they graphically detail characteristics of the environment from which fuzzy elements exist. There are mainly four distinct fuzzy membership functions that will be discussed within this work: S-shaped (sigmoidal), Pi (π) - shaped, Triangular-shaped, and Trapezoidal-shaped.

The S-shaped membership function can be referred to as growth and decline curves (Cox, 1994). Both, decline and growth curves, usually begins at one extreme level (either full or no membership) of membership and progresses towards the opposite extreme. This S-shaped curve and its linear counterparts will be utilized within this research.

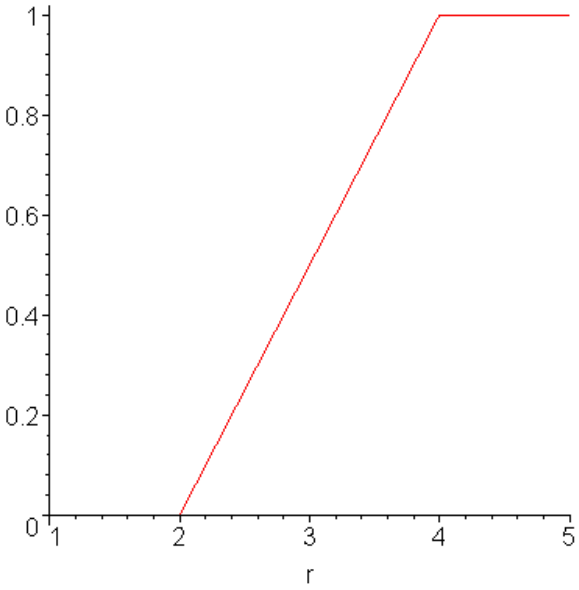


Figure 8 S-shaped Curve

Pi (π) - shaped mapping functions, the other commonly used form of Fuzzy Set membership graphing functions, looks similar to the Greek letter Pi (π). Cox states that this function is frequently used because it allows for the gradual progression of a fuzzy variable from complete non-membership (0.00) to complete membership (1.00) and complete membership (1.00) to complete non-membership (0.00), within the set.

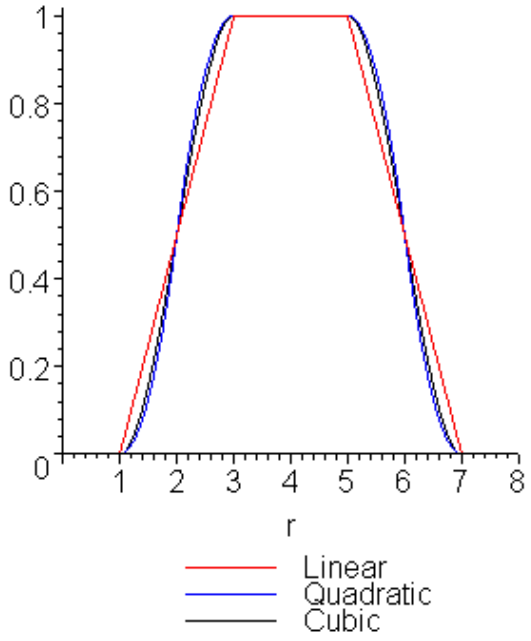


Figure 9 Pi-Shaped Curve

The Triangular-shaped membership function can be used when there is a suspected linear relationship that pivots about an extreme optimal point of complete membership (1.00).

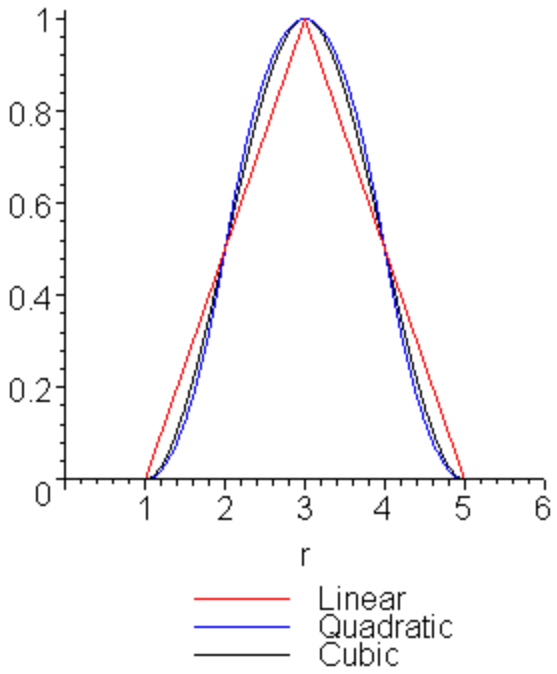


Figure 10 Triangular-Shaped Curve

Finally, the Trapezoidal-shaped function is very similar to the Triangular-shaped function but does not have a single optimal point and may be asymmetrical.

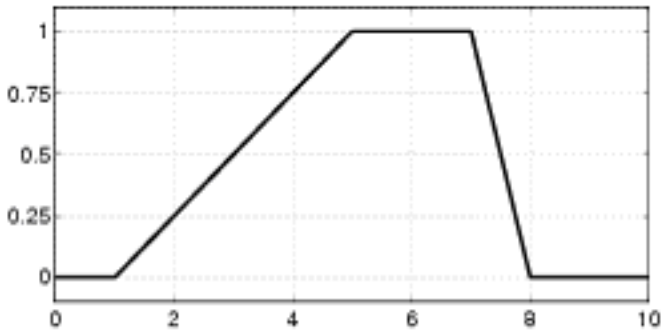


Figure 11 Trapezoidal-Shaped Curve

These examples of possible Fuzzy membership functions delineate the level of membership of a fuzzy variable within a fuzzy set. Graphically it is also possible that Fuzzy membership functions are composed of combinations of these different functions.

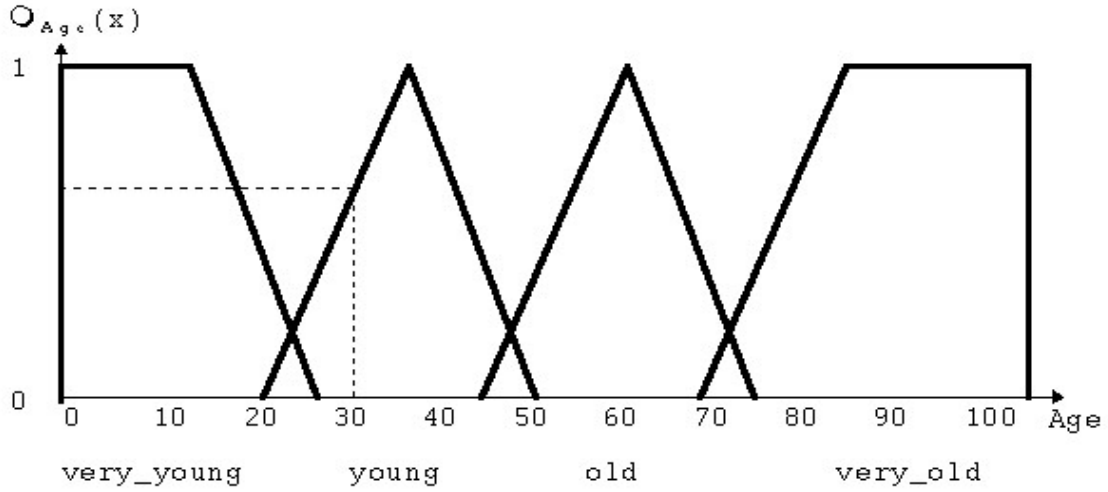


Figure 12 Mixed-Combination Curves

The versatility of FST allows for many different applications. Hence the robust nature of FST even allows for augmented model development as new knowledge is acquired; hence an advantage over other methods may be realized when used to model human engagement.

Human Engagement Equation Form

The following equation is the hypothesized theoretical form of the human engagement state.

Human Engagement =

$$\mathbf{W_1 F_1} \otimes W_2 F_2 \otimes W_3 F_3 \otimes W_N F_N$$

Where:

W_1 = Relative Human Engagement Factor Weight

F_1 = Level of Human Engagement Factor Existence

$\otimes$ = Unknown Operand $W_N F_N$ = Unknown (N) number of factors

The unknown operand was used in the theoretical form; however the summation of the factors suffices for this research.

Human Engagement (F1) State Equation Form

Now that the high level theoretical form has been stated, the next lowest level equation form of the human engagement factor may be seen next.

$$\text{Human Engagement } (F_1) = x_1 g_1 + x_2 g_2$$

Where:

x_1 = Relative Physiological Response Factor Weight

g_1 = Level of Physiological Response Factor Existence

x_2 = Relative Human Perception and Cognitive Demands Factor Weight

g_2 = Level of Human Perception and Cognitive Demands Factor Existence

Fuzzy Set S – Shaped Membership Function Curve

Subject Matter Experts SME's set "Ideal" Fuzzy Membership Function Curves in this research. Actual observation based Fuzzy Membership functions can then be created. The Histogram (Class Interval) development method is dependent on empirical data or uses inputs provided by SME's. First the determined number of fuzzy linguistic levels, i.e. bins/classes, is established; the number of linguistic level is five within this research. Next the range of the empirical data can be used to determine bin (class) interval. The histogram range method helps to ensure that the probability of observing various possible outcomes is equal across categories, or in this case, linguistic levels. For instance, if the extreme boundary points of the fuzzy linguistic variables where treated as points, then it is logical to have an ideal/theoretical class interval of 0.33 (instead of 0.20) if 5 classes (Fuzzy linguistic levels) are used and the range is 1.00, from the lowest degree of membership (0.0) to the highest degree of membership (1.00). In essence only 3 classes have a width or interval, since at the extremes resides discrete values of 1.00 and 0.00 which indicate full membership or no membership. The following figure is an ideal theoretical linear Fuzzy Membership function, which is a solid start point for fuzzy data analysis.

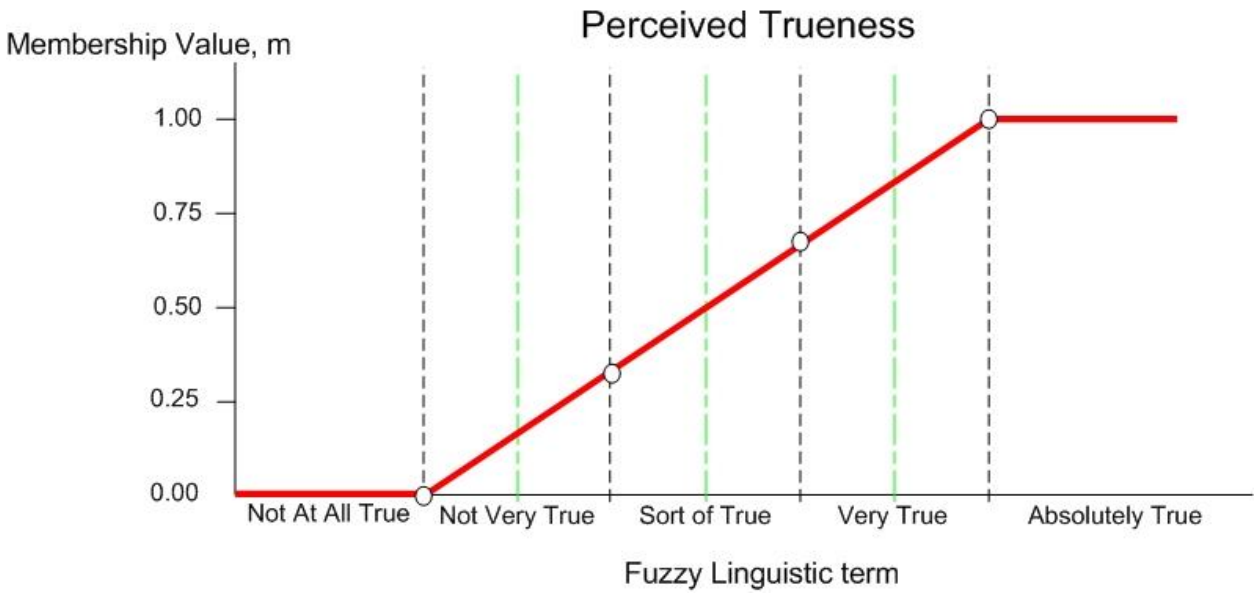


Figure 13 Ideal Theoretical Fuzzy Membership Function

The class interval calculation steps can be seen next. Class Interval Creation Steps include:

1. Select (N) = the number of observations or data points
2. Determine the range (R) of the data by finding the difference between highest and lowest values
3. Determine the number of K classes: K = 5 for this research
4. The class interval (h) or width of each fuzzy linguistic level can be calculated as the range divided by the number of classes: h = R/K

(Mendenhall, 1994)

Though, hence in this research where the extreme points were defined as equal width intervals, and after the class interval has been determined, the identified center point of the interval was

used to defuzzify the fuzzy linguistic variables (participant responses). In this research the class intervals were 0.200 units wide. Once again, five class intervals were chosen each of equal length to ensure that the probability of observing a specific outcome was equal amongst all possible outcomes within the research problem space. The following table 12 delineates the detailed class interval composition:

Table 12 Fuzzy Class Interval Composition

ID	Fuzzy Linguistic Variable	Min.	Center	Max.
1	Absolutely True	0.800	0.895	1.00
2	Very True	0.600	0.695	0.799
3	Sort of True	0.400	0.495	0.599
4	Not Very True	0.200	0.295	0.399
5	Not at All True	0.000	0.095	0.199

In the next figure the actual initial theoretical Fuzzy Membership function was.

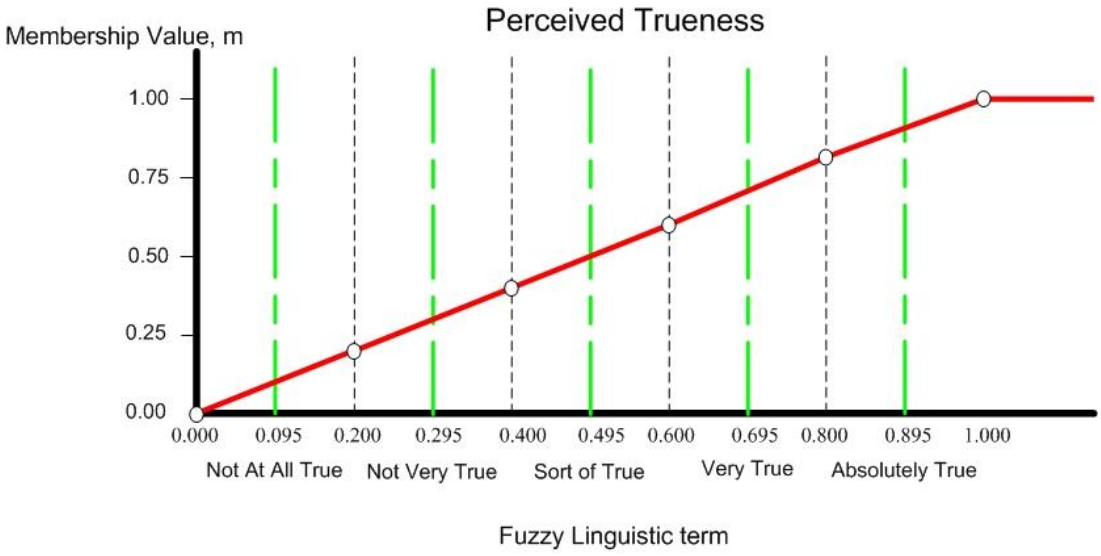


Figure 14 Theoretical Fuzzy Membership Function

Subjects were allowed to respond to the instrument level of trueness in linguistic terms. Initially, the membership function had been created but it was expected that the data would help to refine the initial fuzzy membership graph design. What was expected to change was the interval width once data had been collected. Maximum and minimum values were used to indicate the boundaries for each interval and the midpoint value for each interval was used to indicate the numeric value of the linguistic variable category. For example, a subject may have made a "Very True" response and a value of 0.695 was assigned. Another subject's response to the same type of question may have resulted in a "Sort of True" response with a 0.495 numeric value. The membership function may change shape based on the frequency distribution of the responses for a specific question type and may not display the theoretical linear function characteristics.

Three experimental levels of interactive multimedia types were introduced, Level 1, Level 2, and Level 3, in terms of game popularity and game type. Relative frequency distribution based methods (pollster methods) were used to establish Fuzzy Membership Functions and fuzzify input variables, just as in the case of class interval creation, this is also the case in a crisp set scenario (Lalla, Facchinetti, & Mastroleo, 2004). The initial fuzzy membership functions were derived empirically and will be discussed in the next chapter in conjunction with other empirical data.

Chapter 4 Summary

1. Fuzzy Set Theory vs. Regression Analysis difference include:
    a. Fuzzy Modeling allows for the use of SME input while regression relies solely on empirical data. Also Fuzzy allows for multi-valued qualitative variables versus the binary coding of regression.
    b. Factor confounding is more of a concern in the regression since, while not an issue in the Fuzzy Modeling scenario.
2. Regression Analysis is widely accepted. Regression is limited to the range of collected data, extraneous error will be introduced into the model.
3. Regression foundational assumptions should be met prior to use:
    a. Normally Distributed and Uncorrelated Error
    b. Sampling distributions for regressor should be normally distributed
    c. All factors in the analysis should exhibit independence
4. Fuzzy Sets are similar to Classical Sets
    a. Partial Set Membership is supported in Fuzzy Set Theory.
    b. Fuzzy sets can be manipulated to determine the Union and Intersection of sets.
5. Graphical representations of Fuzzy set membership exists
    a. S-shaped Sigmoidal
    b. Pi-Shaped
    c. Triangular-shaped
    d. Trapezoidal-shaped

6. Fuzzy Mathematical Models are robust and adaptable to new variables and changing conditions.
7. Five Fuzzy Linguistic Variables were used in this research, similar to Likert scaling.
8. Pollster methods for creating Fuzzy Membership functions were used.

Fuzzy Set Theory was designed to address the ambiguity and vagueness of real systems. An experimental research study was conducted with the intent of assessing engagement levels of humans while interfacing interactive multimedia.

The next chapter 5 will examine the applied theory and experimental results of Fuzzy Mathematical Modeling. The completed human engagement equation will be addressed.

CHAPTER FIVE: EXPERIMENTAL RESULTS

Study Results

The following chapter will delineate the actual applied theory from Chapter 4 and the experimental results of this research. The focus of this research was that of a design study in which the acquired empirical data was used to assist in expressing the viability of the research methodology. The experimental aspect of the research consisted of two distinct parts:

1. Pilot Runs
2. Full Experimental Runs

Pilot Runs

The pilot study consisted of five empirical observations. The goal was to observe physiological and perceived cognitive changes as they correlated with game-play. Rapid settings on GSR equipment were used in order to detect transient spikes in GSR voltage, some of these instances lasted from milliseconds to seconds in duration. Initially the amount of data was overwhelming in addition to the synchronization of observed video frames of game-play. A more efficient way was devised and the experimental setup was verified and deemed ready for full experimental runs. The pilot was simplified for full runs in order to ensure that research was streamlined within constraints. Simplification of the pilot runs included not using video data which was an initial attempt to synchronize physiological and cognitive perception data with game-play action.

Experimental Sample Size

The sample size used in this experiment was N = 33. There were more than 39,000 data points collected and analyzed in the Physiological Response Arousal (g_1) factor assessment. The Heart Rate and GSR apparatuses were set at their lowest operational settings, collection frequencies 50 and 100 hz. As for the Human Perception and Cognitive Demands (g_2) factor, 295 data points were collected and analyzed. The collection of real world data was a necessary in order to test the viability of the fuzzy theoretical approach.

Full Experimental Runs

During the Full Experimental Runs empirical data was collected and used to determine factor level degree of existence. Also, AHP factor weightings were derived as delineated in previous chapter 4. A SME with background knowledge of cognition and arousal in interactive multimedia, answered questions in the Fuzzy Mathematical Modeling of Human Engagement Survey (Appendix B). The results of the survey and resultant AHP factor weightings can be viewed in the following resultant summary Tables 13, 14, and 15. A brief description of the content of tables 13 - 15 includes:

1. Indentified factors are labeled in column 1 and row 1
2. Numerical value ratings from 1 – 9 were determined by a SME and entered for each factor pair-wise comparisons as dictated under AHP methods.

Once again, the factors that were identified in this research, that impact human engagement (F_1) were:

1. Physiological Response Arousal: g_1
2. Human Perception and Cognitive Demands: g_2

The top level AHP factor weightings were:

Table 13 Top Level Resultant Summary Table

AHP	**g_1**	**g_2**
g_1	1	1
g_2		1

Sub-factors in Table 14 that were identified in this research to impact human engagement from a physiological perspective were:

1. Heart Rate: h_1
2. GSR: h_4

These physiological factors were analyzed with the following results were as follows:

Table 14 Section 1 Resultant Summary Table

AHP	**h_1**	**h_4**
h_1	1	5
h_4		1

The next table will include the following sub-factors used to indicate the Perception and Cognitive aspect of the fuzzy framework:

1. Content Understanding: j_1
2. Collaboration/Teamwork: j_2
3. Problem Solving: j_3
4. Affective/Emotional State: j_4
5. Communication: j_5
6. Self Regulation: j_6
7. Realism and Fidelity: j_7

The resultant factoring weighting ratings were as follows:

Table 15 Section 2 Resultant Summary Table

AHP	j_1	j_2	j_3	j_4	j_5	j_6	j_7
j_1	1	7	1	3	5	3	3
j_2		1	7	8	3	8	8
j_3			1	3	5	3	4
j_4				1	9	1	3
j_5					1	8	8
j_6						1	2
j_7							1

The final level of factors that were aggregated to define the j_6 factor (Self Regulation) can be seen in the following table. Motivation (k_1), User Control/Entitlement (k_2), Self Regulation Misc (k_3), factors were analyzed.

Table 16 Section 3 Resultant Summary Table

AHP	k_1	k_2	k_3
k_1	1	1	1
k_2		1	1
k_3			1

After the value ratings were entered into the AHP software (Expert Choice 11.5), the AHP factor weighting results were calculated as follows:

Table 17 AHP Factor Weighting Results

Factor/Response Name	AHP Factor Weighting
Human Engagement: F_1	*
Physiological Response Arousal: g_1	**0.500**
Human Perception and Cognitive Demands: g_2	**0.500**
Heart Rate: h_1	**0.833**
GSR: h_4	**0.167**
Content Understanding: j_1	**0.036**
Collaboration/Teamwork: j_2	**0.043**
Problem Solving: j_3	**0.062**
Affective/Emotional State: j_4	**0.109**
Communication: j_5	**0.180**
Self Regulation: j_6	**0.252**
Realism and Fidelity: j_7	**0.319**
Motivation: k_1	**0.333**
Factor/Response Name	**AHP Factor Weighting**
User Control/Entitlement: k_2	**0.333**
Self Regulation Misc.: k_3	**0.333**

The following diagram is an Interrelations Diagram that delineates the relationships between each factor in the engagement definition model. The AHP Factor Weightings were also included. The figure shows the hierarchical structure of the human engagement factor.

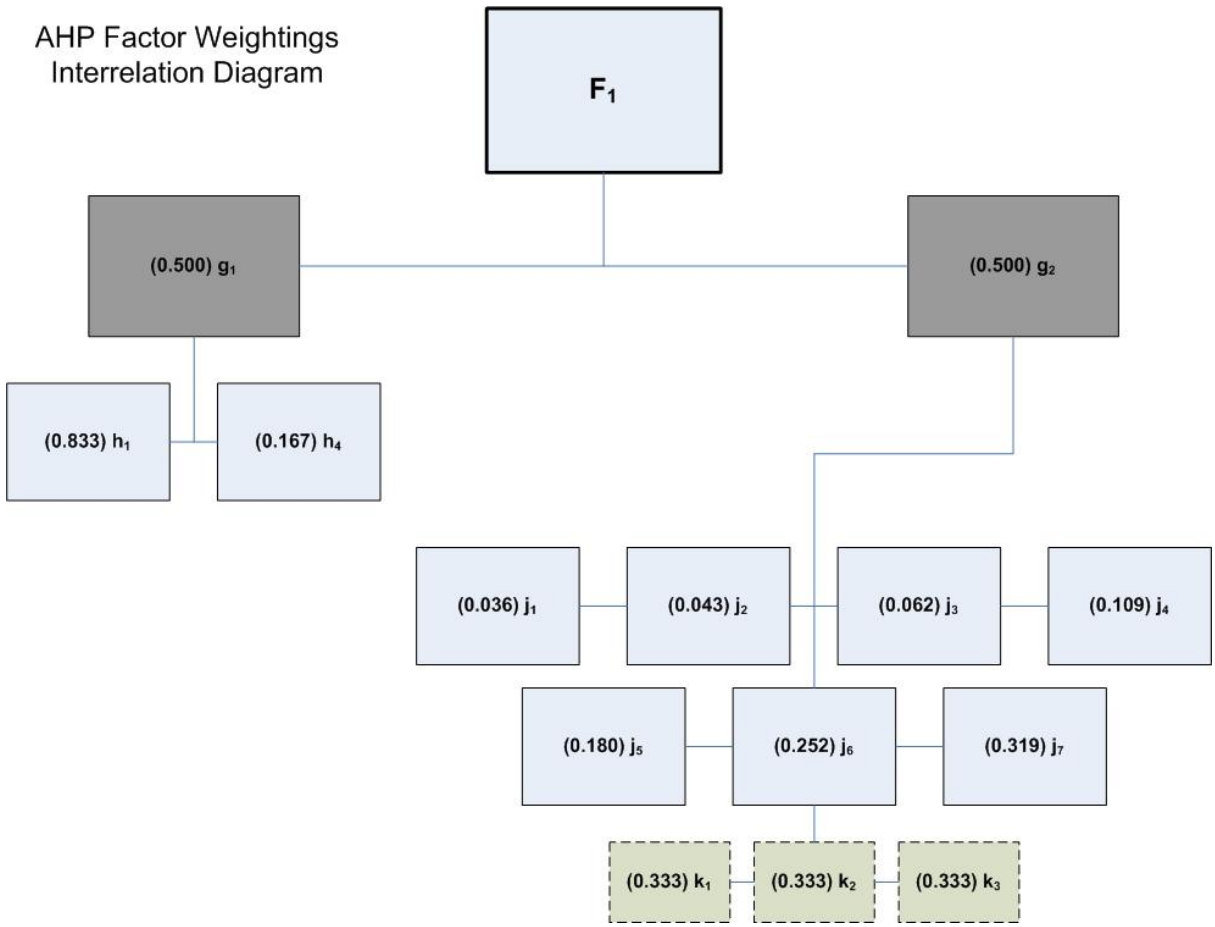


Figure 15 AHP Factor Weightings Interrelation Diagram

In order to obtain these calculated results, a computer software package that has AHP capability should be used. The next section will describe the software used in this research.

AHP Analysis Software

The AHP software that was used in this research was:

1. Expert Choice Trial 11.5.1472
2. Copyright© 1982-2009 Expert Choice, Inc. All rights reserved.
3. Database Version: 3.04
4. Limitations:
    a. Maximum Number of Participants – 3
    b. Maximum Number of Nodes per Cluster – 9
    c. Maximum Number of Alternatives - 8

A full version of the Expert Choice software would remove the noted limitations. The maximum number of Nodes (child nodes) would be beneficial if a more detailed analysis is desired. Also, the number of participants refers to the number of SME's that may simultaneously contribute to the analysis, i.e. provide insight into the calculation of the AHP factor weightings.

Engagement Factor Level Assessment

Physiological and Human Cognitive and Perception data was collected to aide in the assessment of which identified factors impacted human engagement, and to what degree of impact existed. The physiological responses required no external (external to sensory equipment) quantification

techniques since their measures were numerical values and units of measure in terms of voltages (V) and beats per minute (BPM).

Assessing the degree or level of existence/trueness of qualitative factors that impact participant engagement while the participant interfaces an interactive multimedia application, is a research objective of this work. Utilizing Fuzzy Mathematical Modeling, as outlined, in theory, from the previous Chapter Four, was the main premise of the actual experimental portion of the research.

Numerical positive values on the continuum from [0 - 1] are used in calculations. As in the previous case for the Average Heart Rate (- 5.16%) and GSR percent change (-17.14%) from baseline for the COD2 media, in table 18, the numerical values would be 0 and 0 respectively, since they were negative. In the opposite or maximum case, the Average GSR percent change (139.00%) for the SPL media numerical value would be 100%, since the percent change was well above 100%.

Table 18 Physiological Response Measures Results

Media Name	BASAL HEART RATE (BPM)	BASAL GSR (V)	AVG. HEART RATE (BPM)	AVG. GSR (V)	AVG. HEART RATE % CHANGE	AVG. GSR % CHANGE
SPL	73	0.492	75	0.915	2.48%	139.00%
RB6	75	0.623	77	0.715	2.49%	38.87%
COD2	77	1.177	73	0.975	-5.16%	-17.14%

Media Name	BASAL HEART RATE (BPM)	BASAL GSR (V)	AVG. HEART RATE (BPM)	AVG. GSR (V)	Adjusted AVG. HEART RATE % CHANGE	Adjusted AVG. GSR % CHANGE
SPL	73	0.492	75	0.915	2.48%	100.00%
RB6	75	0.623	77	0.715	2.49%	38.87%
COD2	77	1.177	73	0.975	0.00%	0.00%
Avg.	**75**	**0.764**	**75**	**0.868**	**1.66%**	**46.29%**

Human Engagement Level Calculation

After the data was collected the final Human Engagement Level Heuristic was calculated. The method of the calculation and analysis of the Physiological (quantitative) factor and the Human Perception and Cognitive Demands (qualitative) factor were treated slightly differently.

The physiological data was recorded via biosensors (Heart Rate Sensor and GSR Galvanic Skin Response). To ensure a normalized unit of measure between the physiological data and the human perception data, the physiological data was determined by assessing the percent change in Heart Rate and GSR reading from participant baseline measures. The HPCD data was then derived via direct participant verbal responses. The degree level of existence of the human perception data was determined by the percent frequency of occurrence of participant's responses in the HPCDI instrument.

The nature of the Fuzzy Mathematical model only allows for a theoretical score maximum and minimum score of 1 and 0, respectively. For ease in using the model, the resultant Human

Engagement factor level would then be multiplied by 100, which would increase the theoretical maximum score to 100.

Equation 1 Maximum Theoretical Human Engagement Score

$$\text{Maximum Theoretical Human Engagement Score } (F_1) =$$

$$x_1 g_1 + x_2 g_2 = 0.500\,(1) + 0.500\,(1) = 1 * 100 = 100$$

Where:

x_1 = Estimated AHP Physiological Response Factor Weight

g_1 = Level of Physiological Response Factor Existence

x_2 = Estimated AHP Human Perception and Cognitive Demands Factor Weight

g_2 = Level of Human Perception and Cognitive Demands Factor Existence

We then generated an actual Fuzzy Human Engagement heuristic score.

HPCD Fuzzy Level Factor Degree of Existence

The fuzzy level factor Degree of Existence for the Human Perception and Cognitive Demands factor was analyzed according the method described in chapter 4. The three levels of media examined within this research were used to provide data used in the fuzzy mathematical model of human engagement.

Graphical Fuzzy Membership Function Diagrams (Frequency Distributions)

The Fuzzy level of existence for all media researched will be discussed in this section. The derived factor Graphical Fuzzy Membership Function diagrams represent the cumulative responses for all three media levels researched. Based on the suite (three levels) of interactive media applications used in this research we can deduce the engagement level of the research participants. The Fuzzy membership functions can be seen in the following figures:

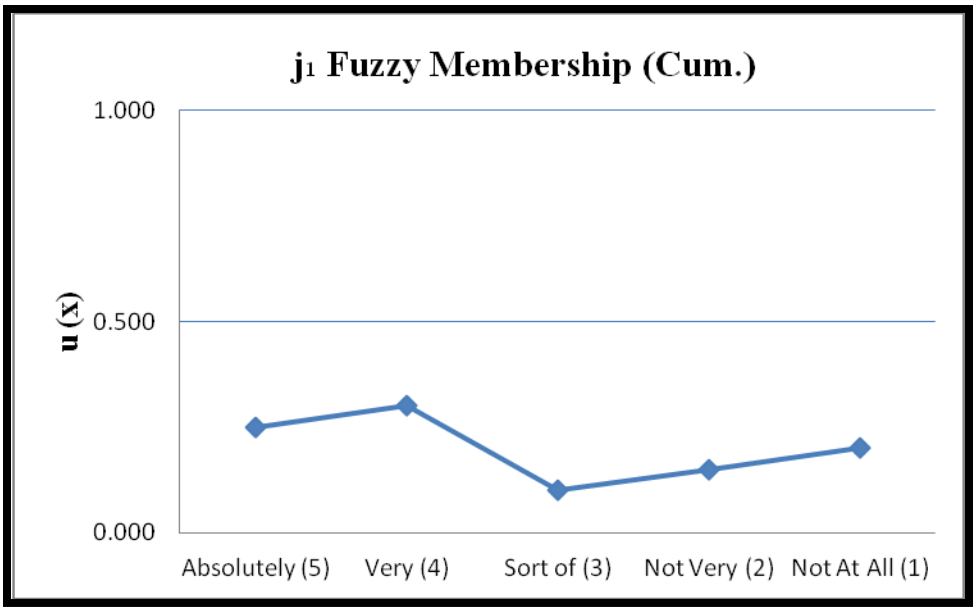


Figure 16 Fuzzy Membership Function Factor: j_1

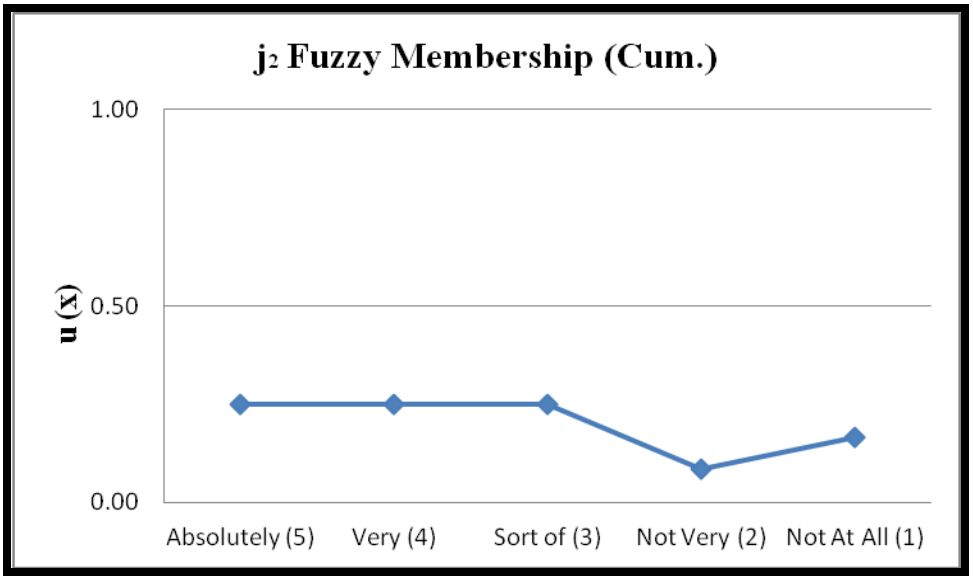


Figure 17 Fuzzy Membership Function Factor: j_2

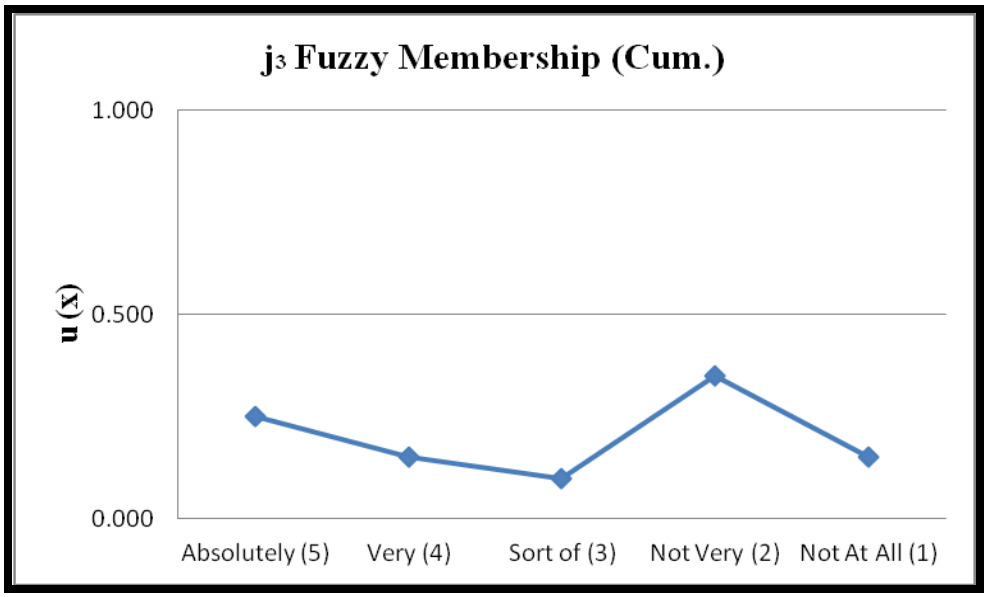


Figure 18 Fuzzy Membership Function Factor: j_3

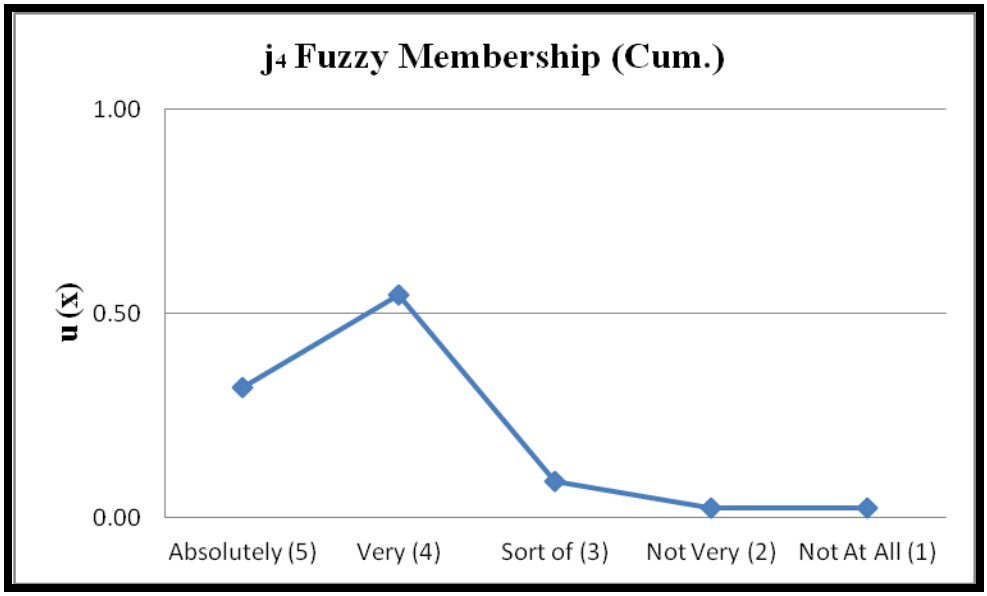


Figure 19 Fuzzy Membership Function Factor: j_4

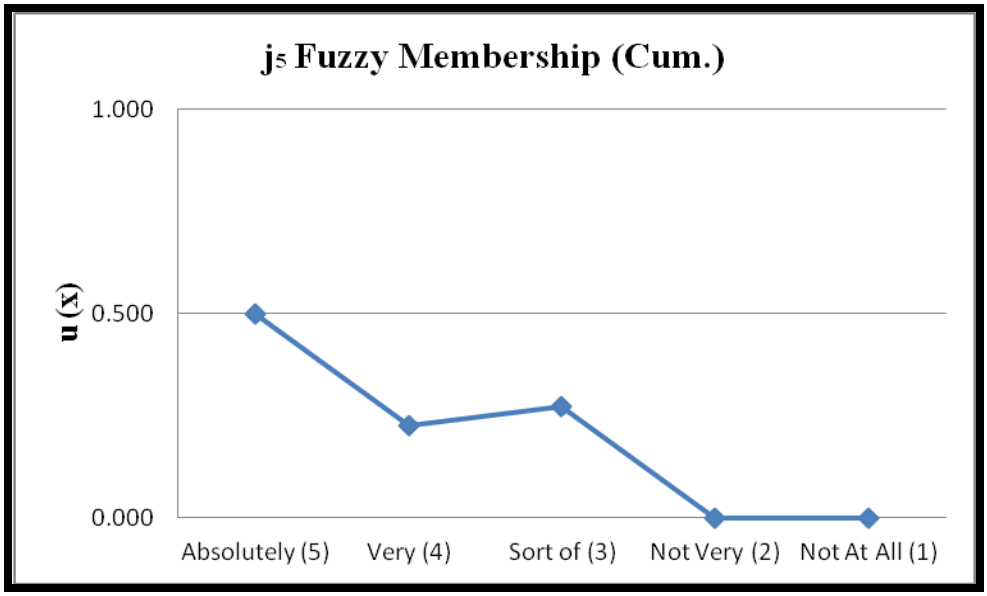


Figure 20 Fuzzy Membership Function Factor: j_5

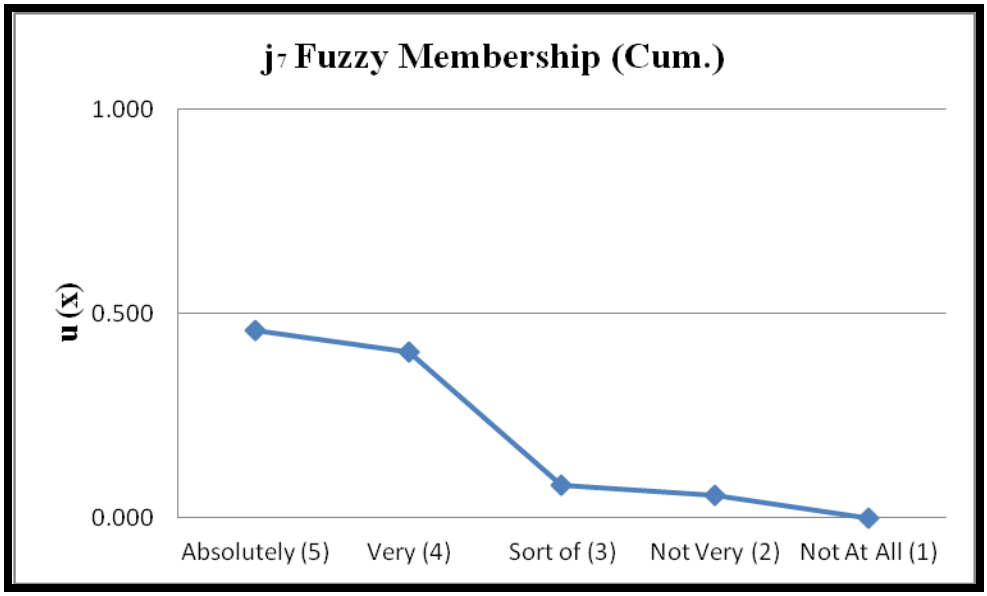


Figure 21 Fuzzy Membership Function Factor: j_7

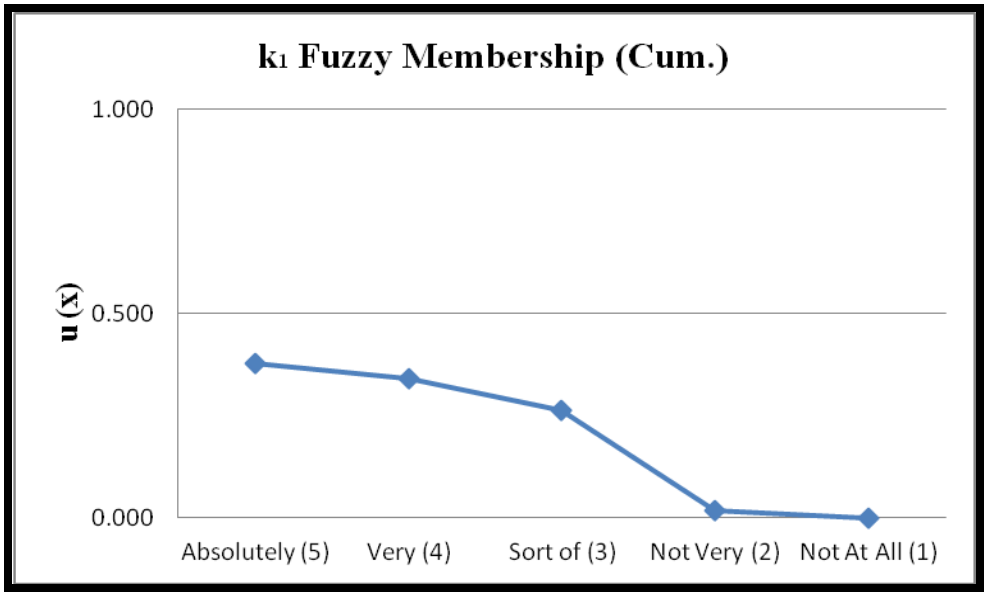


Figure 22 Fuzzy Membership Function Factor: k_1

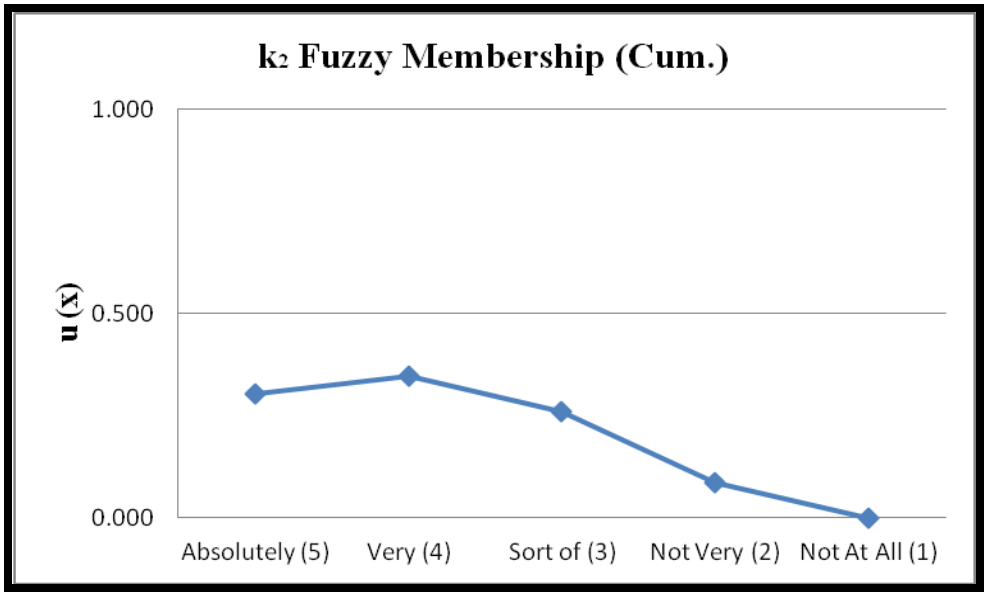


Figure 23 Fuzzy Membership Function Factor: k_2

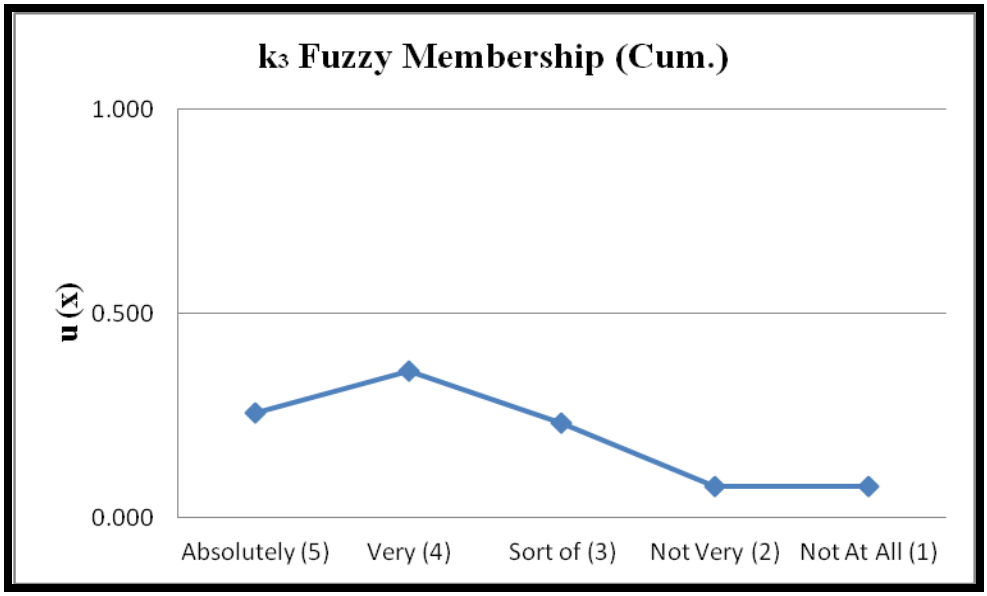


Figure 24 Fuzzy Membership Function Factor: k_3

The following fuzzy set notation is the numerical representation of the previous fuzzy membership diagrams in which the numerator represents the degree of existence/trueness set membership for the factor, while the denominator represents the category label: 5 = Absolutely

True, 4 = Very True, 3 = Sort of True, 2 = Not Very True, 1= Not at All True. Firstly, the fuzzy sets for each Human Perception and Cognitive Demands factor were determined as follows:

1. Content Understanding: j_1
    a. {0.250/5, 0.300/4, 0.100/3, 0.150/2, 0.200/1}
2. Collaboration/Teamwork: j_2
    a. {0.250/5, 0.250/4, 0.250/3, 0.083/2, 0.167/1}
3. Problem Solving: j_3
    a. {0.250/5, 0.150/4, 0.100/3, 0.350/2, 0.150/1}
4. Affective/Emotional State: j_4
    a. {0.318/5, 0.545/4, 0.091/3, 0.023/2, 0.023/1}
5. Communication: j_5
    a. {0.500/5, 0.227/4, 0.273/3, 0.000/2, 0.000/1}
6. Self Regulation: j_6
    a. Motivation: k_1
        i. {0.377/5, 0.340/4, 0.264/3, 0.019/2, 0.000/1}
    b. User Control/Entitlement: k_2
        i. {0.304/5, 0.348/4, 0.261/3, 0.087/2, 0.000/1}
    c. Self Regulation Misc: k_3
        i. {0.256/5, 0.359/4, 0.231/3, 0.077/2, 0.077/1}
7. Realism and Fidelity: j_7
    a. {0.459/5, 0.405/4, 0.081/3, 0.054/2, 0.000/1}

The numerical values contained in the fuzzy sets where then used as the degree of existence of the factor when calculating the human engagement level. For each fuzzy set the maximum member multiplied by its respective category value was used to represent the degree existence of the factor the fuzzy set represented.

Error is inevitable, yet there are ways to measure and mitigate its effects. The next section will address the error uncovered in this research.

Experimental and Instrument Error

The sources of error in this research were mainly AHP factor weighting inconsistency and HPCDI instrument participant inconsistency of responses for each factor of engagement. These measures of error were then compared and contrasted with measured error of an established instrument in chapter 6.

- AHP Inconsistency

AHP inconsistency measures were identified in cases where there were more than two factors where pair-wise comparisons could be performed. In this case, the g_2 Human Perception and Cognitive Demands factor was analyzed. Inconsistency follows the transitive property. The higher the inconsistency measure the more unreliable the AHP factor weighting ratings would be considered. An inconsistency ratio of more than 10% is not readily acceptable, according to the literature. To mitigate inconsistency the number of SME's used to assign the factor weightings should be increased or the subjective goal may need to be redefined and explained. The average

of the factor weighting ratings could then be used. Inconsistency merely measures the logical judgment (precision) of pair-wise comparisons but does not indicate if the assigned ratings are correct or not (accuracy). The inconsistency ratio is directly correlated with Cronbach's alpha. The following table contains the inconsistency measures for factors in this research.

Table 19 AHP Inconsistency Ratios Cumulative

Factor	AHP Inconsistency Ratio
F_1	0.41
g_1	0
g_2	0.41

The AHP overall inconsistency of this research resulted in 0.41 or 41%. The resultant Cronbach's alpha would roughly be (α) = 0.59. Remember the main focus of this research is to show that the fuzzy methodology is viable when defining human engagement. These results confirm that the method is able to identify error and measure it appropriately. Fine-tuning and refinement could then be executed in improvement efforts to reduce error.

- HPCDI Inconsistency

Participant responses should be consistent for items; even the converse statement should be true. In this research we are interested in the positive (increase) factor impact on human engagement therefore true statements about the negative version of a question are in essence opposite. A transformation scale was used to convert respondent statements, see the following table.

Table 20 Fuzzy Linguistic Transformation Scale

(-) Not At All True (0.095)	(-) Not Very True (0.295)	Sort of True (0.495)	(-) Very True (0.695)	(-) Absolutely True (0.895)
(+) Absolutely True (0.895)	(+) Very True (0.695)	Sort of True (0.495)	(+) Not Very True (0.295)	(+) Not At All True (0.095)

For instance, if a participant had a response of "Absolutely True" for a question that was the negative converse, i.e. "You do *not* like the game?" Then the positive response would be "Not At All True" for the question "You like the game?" In essence, the question and response are multiplied by a negative sign, thus turning statements into their equivalent opposite (converse) which is equidistant from the midpoint. In application, human responses yielded a degree of inconsistency that was measurable and consistent with theory.

In the case of analyzing the media levels separately, the media types SPL and RB6 were compared. The media types are very similar in nature and yielded similar physiological data. The following figure shows the Fuzzy Membership functions for the factor k_1.

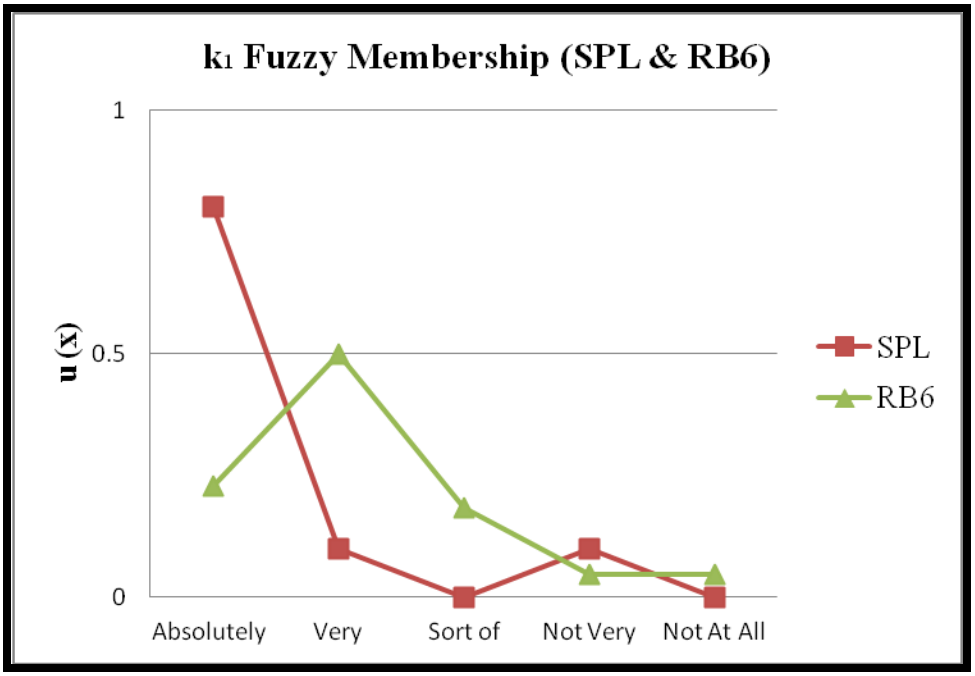


Figure 25 Fuzzy Membership Function SPL and RB6

The k_1 Fuzzy Membership Function for media types SPL and RB6 exhibit similar characteristics. This was expected since their physiological data was highly correlated. Motivation was identified in the literature as being directly correlated with engagement. This research was able to show that the fuzzy methodology was capable of determining the degree of existence of a specific factor with some degree of fidelity; yet error remains. The HPCDI instrument exhibited the following type and degree of error:

1. Inconsistent Participant Response
2. Between Media Level Error

The next section will address the error associated with the HPCDI instrument via ANOVA analysis

- ANOVA Analysis

Participant response consistency was analyzed different ways. The first analysis used the participant's responses for each factor type. HPCDI used paired positive and negative questions for each factor. The pairing allowed for the inconsistency measure. The responses for each question type should not be significantly different. A single factor ANOVA analysis was conducted for each pair, the results were as follows:

SUMMARY FOR SPL FACTOR: j3						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 1	10	5.75	0.575	0.117		
(+) 2	10	4.15	0.415	0.055		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.128	1	0.128	1.485	0.239	4.414
Within Groups	1.552	18	0.086			
Total	1.68	19				

Figure 26 Summary ANOVA Results Factor: j_3

SUMMARY FOR SPL FACTOR: j1						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 3	10	5.95	0.595	0.136		
(+) 4	10	4.95	0.495	0.053		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.05	1	0.050	0.529	0.476	4.414
Within Groups	1.7	18	0.094			
Total	1.75	19				

Figure 27 Summary ANOVA Results Factor: j_1

SUMMARY FOR SPL FACTOR: k3						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 5	10	6.95	0.695	0.053		
(+) 6	10	6.95	0.695	0.027		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	2E-16	1	0.000	0.000	1.000	4.414
Within Groups	0.72	18	0.040			
Total	0.72	19				

Figure 28 Summary ANOVA Results Factor: k_3

SUMMARY FOR SPL FACTOR: k3						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 9	9	5.455	0.606	0.091		
(+) 10	10	4.950	0.495	0.044		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.058	1	0.058	0.881	0.361	4.451
Within Groups	1.129	17	0.066			
Total	1.187	18				

Figure 29 Summary ANOVA Results Factor: k_3

The p-values for each question pair were well above 0.05; 0.239, 0.476, 1.000, and 0.361 respectively. There is no statistical evidence that supports the idea that responses to questions within each pair are significantly different; hence the questions address the same factor. Also, the RB6 media was analyzed with ANOVA as the SPL media.

Now the RB6 media ANOVA may be seen for factors j_4, j_7, k_1, and k_2.

SUMMARY FOR RB6 FACTOR: k1						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 25	11	7.245	0.659	0.031		
(+) 26	11	6.445	0.586	0.059		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.029	1	0.029	0.650	0.429	4.351
Within Groups	0.895	20	0.045			
Total	0.924	21				

Figure 30 Summary ANOVA Results Factor: k_1

SUMMARY FOR RB6 FACTOR: j7						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 27	11	8.445	0.768	0.042		
(+) 28	10	6.75	0.675	0.031		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.045	1	0.045	1.226	0.282	4.381
Within Groups	0.698	19	0.037			
Total	0.743	20				

Figure 31 Summary ANOVA Results Factor: j_7

SUMMARY FOR RB6 FACTOR: k2						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 31	11	8.045	0.731	0.031		
(+) 32	11	7.245	0.659	0.023		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.029	1	0.029	1.096	0.308	4.351
Within Groups	0.531	20	0.027			
Total	0.56	21				

Figure 32 Summary ANOVA Results Factor: k_2

SUMMARY FOR RB6 FACTOR: j4						
Questions	*Count*	*Sum*	*Average*	*Variance*		
(-) 35	11	8.045	0.731	0.039		
(+) 36	11	7.245	0.659	0.039		
ANOVA						
Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	0.029	1	0.029	0.755	0.395	4.351
Within Groups	0.771	20	0.039			
Total	0.8	21				

Figure 33 Summary ANOVA Results Factor: j_4

Once again it was determined that paired questions were not statistically different since p-values for factors j_4, j_7, k_1, and k_2 were 0.395, 0.282, 0.429, and 0.308 respectively.

Equipment Calibration and Sensor Usage Error

The equipment used in this research was provided by QUBIT Systems Inc. The S182 Wireless Exercise Heart Rate Monitor and S220 Galvanic Skin Response Sensor were used to collect physiological data. Further detail on the equipment used in this research may be seen in Appendix E. As the usual case with lab equipment, calibration was enacted to ensure higher quality data, when warranted.

- Wireless Exercise Heart Rate Monitor

The calibration instructions of the Wireless Heart Rate monitor did not exists; simply calibration was not warranted according to manufacturer specification. Other sources of error due to usage inconsistencies such as the following were mitigated:

1. Wireless Signal Transmission Range – The actual range for transmission of the heart rate signal was approximately two meters from the receiver. Participants were encouraged to sit and remain within 1 meter of the wireless signal receiver.
2. Proper Electrode Contact Cleaning – Heart monitor contacts were cleaned after each session with a mild astringent.
3. Physical Strap Adjustments – The physical strap was adjusted according to participant torso girth. The tension of the strap was tight enough to keep the heart rate monitor from sliding yet comfortable enough to not adversely affect participant affective state.

- GSR

The GSR device used in this research was calibrated according to manufacturer specification when deemed appropriate (after every 5 sessions). Interestingly enough, research that uses baseline changes in measurements as its basis, partly reduces the need for constant calibration, since relative measurements are used. Other sources of error that were mitigated were:

1. Participant Hand Movement – Participants were instructed to block or wedge the two fingers which were attached to the GSR electrodes, with the provided apparatus. This act mitigated invalid voltage readings.
2. Excessive Moisture – Excessive moisture was mitigated by drying GSR electrodes between gaming sessions and after gaming stimulus exposure. Participants were also provided with drying wipes prior to gaming sessions.

Model Implementation and Human Engagement Score

Using the fuzzy theory and methodology from earlier chapters in this work, the human engagement score was then calculated. The lower level equations were calculated first in order to create the aggregate scores needed for the final top level calculation. The Human Engagement Sublevel 2 Equation was as follows:

$j_6 = d_1k_1 + d_2k_2 + d_3k_3 = (0.333)(0.337) + (0.333)(0.242) + (0.333)(0.250) =$ **0.276**

Where:

d_1 = AHP Motivation Factor Weighting

k_1 = Motivation Factor

d_2 = AHP User Control/Entitlement Factor Weighting

k_2 = User Control/Entitlement Factor

d_3 = AHP Self Regulation Misc. Factor Weighting

k_3 = Self Regulation Misc. Factor

Then the Human Engagement Sublevel 1 Equation became:

$g_1 = b_1h_1 + b_4h_4 = (0.833)(0.017) + (0.167)(0.463) =$ **0.091**

Where:

b_1 = AHP Heart Rate Factor Weighting

h_1 = Heart Rate Factor

b_4 = AHP GSR Factor Weighting

h_4 = GSR Factor

and

$g_2 = c_1j_1 + c_2j_2 + c_3j_3 + c_4j_4 + c_5j_5 + c_6j_6 + c_7j_7 = (0.036)(0.269) + (0.043)(0.224) +$

$(0.062)(0.103) + (0.109)(0.379) + (0.180)(0.448) + (0.252)(0.276) + (0.319)(0.411) =$ **0.348**

Where:

c_1 = AHP Content Understanding Factor Weighting

j_1 = Content Understanding Factor

c_2 = AHP Collaboration/Teamwork Factor Weighting

j_2 = Collaboration/Teamwork Factor

c_3 = AHP Problem Solving Factor Weighting

j_3 = Problem Solving Factor

c_4 = AHP Affective/Emotional State Factor Weighting

j_4 = Affective/Emotional State Factor

c_5 = AHP Communication Factor Weighting

j_5 = Communication Factor

c_6 = AHP Self Regulation Factor Weighting

j_6 = Self Regulation Factor

c_7 = AHP Realism and Fidelity Factor Weighting

j_7 = Realism and Fidelity Factor

Finally, the Human Engagement Top Level Equation was:

$\mathbf{F_1} = a_1g_1 + a_2g_2 = (0.500)(0.091) + (0.500)(0.348) = 0.220 * 100 =$ **22.0**

Where:

a_1 = AHP Physiological Response Arousal Factor Weighting

g_1 = Physiological Response Arousal Factor

a_2 = Human Perception and Cognitive Demands Factor Weighting

g_2 = Human Perception and Cognitive Demands Factor

According to the top level equation, the Human Engagement factor cumulative score is 22. This score can then be used to compare and contrast other media systems on a common normalized scaling. Also, the results for the human engagement score calculation may be viewed in the following table.

Table 21 Cumulative Human Engagement Factor

Factor/Response Name	AHP Factor Weighting	Fuzzy Factor Degree of Existence/Trueness	Result
Human Engagement: F_1	*	*	**0.220**
Physiological Response Arousal: g_1	0.500	0.091	**0.046**
Human Perception and Cognitive Demands: g_2	0.500	0.348	**0.174**
Heart Rate: h_1	0.833	0.017	**0.014**
GSR: h_4	0.167	0.463	**0.077**
Content Understanding: j_1	0.036	0.269	**0.010**
Collaboration/Teamwork: j_2	0.043	0.224	**0.010**
Problem Solving: j_3	0.062	0.103	**0.006**
Affective/Emotional State: j_4	0.109	0.379	**0.041**
Communication: j_5	0.180	0.448	**0.081**
Self Regulation: j_6	0.252	0.276	**0.070**
Realism and Fidelity: j_7	0.319	0.411	**0.131**
Motivation: k_1	0.333	0.337	**0.112**
User Control/Entitlement: k_2	0.333	0.242	**0.081**
Self Regulation Misc.: k_3	0.333	0.250	**0.083**

The COD2 media type was removed from the equation. Reason for removal of the COD2 results was based on the fact that the media was inherently different than the SPL and RB6 media analysis of using only results from media types SPL and RB6 yields the following engagement factor estimate results.

Table 22 No j_2 or j_5 Factor Human Engagement Factor

Factor/Response Name	AHP Factor Weighting	Fuzzy Factor Degree of Existence/Trueness	Result
Human Engagement: F_1	*	*	**0.238**
Physiological Response Arousal: g_1	0.500	0.137	**0.068**
Human Perception and Cognitive Demands: g_2	0.500	0.340	**0.170**
Heart Rate: h_1	0.833	0.025	**0.021**
GSR: h_4	0.167	0.694	**0.116**
Content Understanding: j_1	0.087	0.209	**0.018**
Problem Solving: j_3	0.08	0.103	**0.008**
Affective/Emotional State: j_4	0.209	0.411	**0.086**
Self Regulation: j_6	0.222	0.329	**0.073**
Realism and Fidelity: j_7	0.402	0.384	**0.154**
Motivation: k_1	0.333	0.392	**0.131**
User Control/Entitlement: k_2	0.333	0.348	**0.116**
Self Regulation Misc.: k_3	0.333	0.249	**0.083**

AHP factor weightings were adjusted after factors Communication: j_5 and Collaboration/Teamwork: j_2, which specifically addressed the team aspect where a participant is in a team member role rather than that of a lead role, were removed from the analysis.

Next, table 23 reveals that removal of the COD2 media from the analysis most significantly increased the average GSR percent change; also the average Heart Rate percent change increased.

Table 23 Physiological Response Measures Results SPL & RB6

Media Name	BASAL HEART RATE (BPM)	BASAL GSR (V)	AVG. HEART RATE (BPM)	AVG. GSR (V)	AVG. HEART RATE % CHANGE	AVG. GSR % CHANGE
SPL	73	0.492	75	0.915	2.48%	100.00%
RB6	75	0.623	77	0.715	2.49%	38.87%
Avg.	**74**	**0.558**	**76**	**0.815**	**2.49%**	**69.44%**

Another change and improvement resulting from removing the two factors, included reducing the AHP inconsistency ratio to 0.03 from 0.41, which resides within an acceptable range, see table 24.

Table 24 AHP Inconsistency Ratio SPL & RB6

Factor	AHP Inconsistency Ratio
F_1	0.03
g_1	0
g_2	0.03

Though the previous discussion referred to the removal of factors that address items of the designed media, the overall human engagement framework of this research should be tailored to the specific observed media. The team related factors (Collaboration/Teamwork: j_2 and Communication: j_5) of this research are still valid; yet further insight into understanding the complete team component in defining human engagement, may be an opportunity for future research.

Chapter 5 Summary

1. The experimental sessions consisted of a small Pilot run and Full experimental runs.
2. Physiological measures of Heart Rate and GSR were collected while study participants interfaced with 3 different interactive multimedia types, SPL, RB6, and COD2.
3. Heart Rate data did not have a greater percent change from baseline when compared to that of GSR.
4. A SME utilized AHP to determine the factor weightings of the engagement equation. A measure of inconsistency was then used to determine if the factor weightings were acceptable.
5. An inconsistency measure of 0.41 was recorded for the Human Engagement equation which included all factors; note, a measure of less than 0.10 is desirable. Removing factors Collaboration/Teamwork: j_2 and Communication: j_5 from the analysis reduced the inconsistency measure to 0.03.

6. The inherent difference in the types of media that included team collaboration versus those that did not, was reason to shift emphasis to the analysis of the SPL and RB6 media (they did not contain majority team/follower components).
7. Fuzzy Membership Function diagrams were derived for each factor. Also, Fuzzy sets for each factor were derived based on participant responses to the HPCDI questionnaire.
8. A Human Engagement factor score was derived for the research; $F_1 = 22.0$ (cumulative includes all factors) and 23.8 (with team factors removed). The highest theoretical Engagement score is 100.
9. An ANOVA analysis was conducted to determine the consistency and accuracy of the HPCDI questions. It was determined that the paired positive and negative type questions (for each factor), of the HPCDI, were statistically the same, i.e. they measured the same factor.

The development of the Fuzzy Mathematical Model of Human Engagement was completed. Actual data was then used to derive a human engagement score. The next chapter 6 will discuss what instrument was used to validate the fuzzy methodology.

CHAPTER SIX: MODEL VALIDATION

Likert and Ordinal Scaling Methods

Likert, a type of ordinal scaling method, is one of the more common methods used to quantify qualitative aspects of human behavior and cognitive assessment.

Model Validation Sample Size

The validation sample size that was used in this research was N = 10, or that 10 completed questionnaires (Engagement) were assessed. Five completed questionnaires per each media type (SPL & RB6) were examined. The sample size was not intended to represent statistical significance; however the intent was to determine the feasibility of the fuzzy methodological assessment of human engagement. The exact Likert-based questionnaire used will be discussed in the next section.

Interactive Multimedia Behavior and Perceptions Instrument (ITC-SOPI)

Traditionally measures of qualitative and perceived psychological state mainly included post-stimulus questionnaires. A few examples of these types of questionnaires and inventories include:

1. Witmer and Singer Immersion Tendency Questionnaire (ITQ) and Presence Questionnaire (PQ)

2. Lombard & Ditton Presence Questionnaire
3. Slater-Usoh-Steed (SUS) Presence Questionnaire
4. The Independent Television Commission Sense of Presence Inventory (ITC-SOPI)

The ITC-SOPI instrument was created by Dr. Jane Lessiter and others (Lessiter, et al 2001) from the University of London in a collaborative effort with the former Independent Television Commission (currently known as the Office of Communications, Ofcom). Though in part designed to measure presence in virtual environments, the ITC-SOPI has been applied across various media types including IMAX movies, television, and computer/video gaming applications; hence the ITC-SOPI has been deemed appropriate for this research and will be used to validate the Fuzzy Human Engagement approach. Information about the development of the ITC-SOPI consists of: as of 2001 over 600 completed surveys were used to estimate the reliability of the instrument. According to Google Scholar®, currently more than 239 identified sources have cited the original source of the ITC-SOPI. The following discussion of the ITC-SOPI begins with the basis of the instrument, which identifies four main areas:

1. Spatial Presence
2. Engagement
3. Ecological Validity/Naturalness
4. Negative Effects

The Engagement section (13 items) of ITC-SOPI was used in conjunction with the other areas and was addressed by study participants. The ITC-SOPI instrument consisted of 38 items. A

Five-point Likert scale ("Strongly Disagree 1" , "Disagree 2", "Neither Agree nor Disagree 3", "Agree 4", and "Strongly Agree 5") was used to assess the participant's study experience for each question. A brief description for each of the identified category of the ITC-SOPI instrument states:

1. The Sense of Physical Space refers to the perceived spatial location of the participant in the mediated environment.
2. Engagement refers to the psychological and affective state of the participant during and after exposure to the mediated environment.
3. Ecological Validity/Naturalness refers to how real the environment feels in relation to the "real world".
4. Negative Effects mainly refer to physical mal-effects of participants during and after exposure to the mediated environment.

The specific version of the ITC-SOPI instrument used for validation was:

1. ITC-SOPI © i^2 Media Research Ltd.
2. Copyright Year: 2004
3. Independent Television Commission, March 2000, & Goldsmiths University of London (Lessiter, et. al, 2001)

Study participants were exposed to the game stimulus/video and were then given access to the ITC-SOPI questionnaire to be completed after game-play/video. After the ITC-SOPI data was collected standard descriptive statistics and ANOVA analyses were conducted. The results were

then compared and contrasted with the existing collected Human Perception and Cognitive Demands data from the Fuzzy methodology.

The Results and Analysis

The following table lists the types of questions contained within the Engagement section of the ITC-SOPI.

Table 25 ITC-SOPI Engagement Questions

ID	ITC-SOPI Engagement Questions
A1	I felt sad that my experience was over
A3	I had a sense that I had returned from a journey
A4	I would have liked the experience to continue
A5	I vividly remember some parts of the experience
A6	I'd recommend the experience to my friends
B1	I felt myself being 'drawn in'
B2	I felt involved (in the displayed environment)
B3	I lost track of time
B8	I enjoyed myself
B16	My experience was intense
B17	I paid more attention to the displayed environment than I did to my own thoughts (e.g., personal preoccupations, daydreams etc.)
B30	I responded emotionally
B32	The content appealed to me

- ITC-SOPI Engagement Analysis

The following table contains descriptive statistics of the Engagement Scores for the ITC-SOPI after a study participant was exposed to 10 minutes of the SPL and RB6 interactive multimedia types. Thirteen questions were identified in the ITC-SOPI instrument as pertaining to the

Engagement category. Ten completed ITC-SOPI questionnaires, that answered the 13 questions of the Engagement factor, were used in the analysis. Though, note that this research and the ITC-SOPI's definition of engagement are not exactly the same; however this analysis provided insight into the validity of the Fuzzy methodological approach in defining engagement. The following figure shows the results of an ANOVA analysis on the Engagement (13 questions) section.

SUMMARY ITC-SOPI Engagement SPL & RB6

Questions	*Count*	*Sum*	*Average*	*Variance*	*Std. Dev.*
A1	10	36	3.6	0.489	0.699
A3	10	44	4.4	0.489	0.699
A4	10	45	4.5	0.500	0.707
A5	10	46	4.6	0.267	0.516
A6	10	43	4.3	0.456	0.675
B1	10	46	4.6	0.267	0.516
B16	10	41	4.1	0.322	0.568
B17	10	42	4.2	0.400	0.632
B2	10	46	4.6	0.267	0.516
B3	10	45	4.5	0.278	0.527
B30	10	33	3.3	0.233	0.483
B32	10	39	3.9	0.100	0.316
B8	10	37	3.7	0.456	0.675
Average			4.177	0.348	0.579

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups/Questions	22.231	12	1.853	5.326	0.000	1.836
Within Groups/Questions	40.700	117	0.348			
Total	62.931	129				

Figure 34 Summary ANOVA ITC-SOPI Engagement SPL & RB6

The p-value of 0.000 confirms that the identified 13 questions are statistically different or that responses were from different sources. The next table shows ANOVA results for the ITC-SOPI instrument versus the Fuzzy methodology based questions of the HPCDI. The following items were considered in the analysis:

1. Factor/Questions – Refers to the name of the instrument, media type, and the factors that were addressed. The question numbers are also included. (Questions can be seen in Appendix F for the HPCDI)
2. MSE_{wit} - Mean Square Error within groups, or average sample variance.
3. MSE_{bet} - Mean Square Error between groups of questions.
4. VAR_{max} – The maximum variance of the group of questions analyzed
5. $STDEV_{max}$ - The maximum standard deviation of the group of questions analyzed.
6. F – The F-test statistic value of the sample. F is a ratio of the MSE_{bet} /MSE_{wit}
7. P-Value – The probability of the test statistic being at least as extreme as the one observed given that the null hypothesis is true. Small p-values indicate statistical significance (there is a difference in observed responses).

A summary of results table can be seen next.

Table 26 ITC-SOPI Validation Summary Analysis

Factor/Questions	MSE_{wit}	MSE_{bet}	VAR_{max}	$STDEV_{max}$	F	P-Value
ITC-SOPI Engagement	0.348	1.853	0.500	0.707	5.326	0.000
SPL (j_1) 3, 4	0.094	0.050	0.136	0.369	0.529	0.476
SPL (j_3) 1, 2	0.086	0.128	0.117	0.342	1.485	0.239
SPL (k_3) 5, 6	0.040	0.000	0.053	0.230	0.000	1.000
SPL (k_3) 9, 10	0.066	0.058	0.091	0.302	0.881	0.361
RB6 (j_4) 35, 36	0.039	0.029	0.039	0.197	0.755	0.395
RB6 (j_7) 27, 28	0.037	0.045	0.031	0.176	1.226	0.282
RB6 (k_2) 31, 32	0.027	0.029	0.031	0.176	1.096	0.308
RB6 (k_1) 25, 26	0.045	0.029	0.059	0.243	0.650	0.429

Each factor in the fuzzy mathematical approach was accounted for; though there are other questions from the HPCDI that were not considered in the analysis. The reason for their omission is that research sessions were kept to a minimum duration. Extremely long sessions would introduce a fatigue factor for research participants; thus potentially skewing physiological and other psychological measures. A strategic sample of questions from the HPCDI that covered all of factor types was chosen. Referring to table 26, the MSE_{wit} for all questions for the SPL and RB6 media is comparable to the ITC-SOPI Engagement section. The average variability in participant responses for each question of the ITC-SOPI is more than 3 times that of the questions from the SPL (factors: j_1, j_3, and k_3) media and more than 8 times that of the RB6 (factors: j_4, j_7, k_1, and k_2) media. This measure states that the consistency of participant responses is higher for the fuzzy method than that of the ITC-SOPI. Also, the standard deviation of participant responses for each question is well below that of the ITC-SOPI. The fuzzy methodology contains no more variability (error) than that of the ITC-SOPI.

Among the SPL and RB6 media, there is statistical evidence that confirms the paired opposing questions more readily and accurately represent the intended factor; their p-values indicate that there is no statistical difference in responses between questions of the opposing pair.

From the validation analysis of this section, it is logical to conclude that the Fuzzy methodology (HPCDI questions) are valid and are a feasible alternative to Likert-based 5-point scaled instruments that measure engagement and other psychological factors in interactive multimedia.

Chapter 6 Summary

1. Likert and Ordinal Scaling Methods are amongst the most common type of psychometric tools.
2. Traditional usage of questionnaires usually happen after a participant's exposure to a media stimulus has occurred.
3. Types of questionnaires reviewed for validation were:
    a. Witmer and Singer Immersion Tendency Questionnaire (ITQ) and Presence Questionnaire (PQ)
    b. Lombard & Ditton Presence Questionnaire
    c. Slater-Usoh-Steed (SUS) Presence Questionnaire
    d. The Independent Television Commission Sense of Presence Inventory (ITC-SOPI)
4. Presence questionnaires most closely resembled the HPCDI of this research.
5. Engagement in other instruments was not defined exactly the same as in this research. There are many definitions of engagement, this research attempts to standardize the approach to defining human engagement.
6. Of the reviewed inventories, the ITC-SOPI was originally designed to be administered across a variety of media types including movies and computer games.
7. The ITC-SOPI was chosen as the instrument to validate the Fuzzy Mathematical Methodology.
8. The Engagement factor of the ITC-SOPI included 13 questions/items. Ten completed surveys were used for each media type SPL (n = 10) and RB6 (n = 10).

9. ITC-SOPI ANOVA analysis reveals that the Engagement question responses were statistically different from each other.
10. The ITC-SOPI questions compared and contrasted to questions of the fuzzy HPCDI revealed that the HPCDI contained less variability than that of the ITC-SOPI, hence the HPCDI did not contain any more error than the Likert-based ITC-SOPI.

The Fuzzy Mathematical definition of human engagement appears to be a viable alternative to more commonly used psychometrics. The next chapter 7 will summarize this research and discuss the future and other possible research interests.

CHAPTER SEVEN: CONCLUSION

Overview and Summary

After coming to the end of this research there were some points of learning and discovery that were experienced. We were able to derive a standard measurement methodology for Human Engagement. By creating a fuzzy methodological framework to define Human Engagement, this action should result in a greater facilitation of technology implementation. A step in defining human engagement for interactive multimedia environments is a positive first effort in addressing the effects of Human Engagement and technologies. Other key findings that were delineated in this research will be summarized in the ensuing discussion.

Chapter 1 Conclusions

Interactive multimedia technology addresses the use of video games, computer games, and other virtual environments created with the intent to educate and train. In the effort to train and educate individuals gaps in the research exist. These gaps include:

1. The lack of standard and systematic approaches to research within interactive multimedia.
2. The concern that human factors such as motivation are not adequately addressed within the game-based literature.
3. The idea that overall, there must be more empirical data to show interactive multimedia effectiveness.

This body of work addressed the need to provide a framework which can be utilized to create a Human Engagement heuristic based on Fuzzy Mathematical modeling. Scientists, government, and the private sector see the need for increasing human productivity and efficiency, in this research the need was addressed by in focusing Human Engagement in the interactive multimedia application area. The use of interactive multimedia (computer, video gaming, and simulations/virtual environments) is a relatively contemporary endeavor. Interactive multimedia usage statistics stated that the average gamer was 33 years old. Overall interactive multimedia sales trends were positive as video and computer game sales topped $7.4 billion in 2006, this being on par with motion picture revenues. Some applications of interactive multimedia used to train and educate included:

1. Medical
2. Military
3. Economic/Governmental
4. Institutions of Higher Learning

The idea of increasing productivity of humans is part of the core ideology of the Industrial and Systems Engineer. Some borrowed ideas from the engineering ideology that were used to develop this interactive multimedia research included:

1. Metrics Development (Management Heuristics)
2. Quality Standards and Metrics

The background information of interactive multimedia and the identified research problem lead to further indentifying the appropriate approach to the review of literature.

Chapter 2 Conclusions

Eight major broad fields of study reviewed in this research for their relevant contribution to the interactive multimedia body of knowledge included:

1. Computer Sciences
2. Computer-based Learning
3. Mathematical Modeling
4. Psychology and Human Cognitive Sciences
5. Social Sciences
6. Industrial and Systems Engineering
7. Human Resource Management
8. Educational & Training Systems

Within the aforementioned areas of study, a human engagement definition, relevant topic areas, and key personnel/institutions were identified and cited.

Within the area of Computer Science, engagement was viewed more from a hardware/software design and human interface & usability perspective. The identified game type of interest within in this research was the MMORPG (Massive Multiplayer Online Role Play Game), with a squad-

based functionality. Such a game type embodies many of the common human social interactive characteristics of an educational classroom environment.

Computer-based Learning, defined as the use of computers or electronic computing devices which are the center of the educational and training experience addressed engagement and learning from another perspective. The Educational Technology Movement of 1994 was at the core of the literature for this study area within this research. The areas of concern addressed by the movement included:

1. The professional development of teachers
2. Hardware access
3. Connectivity
4. Digital content

These four areas were the underlying basis of online and distance learning; which provided many with access to education regardless of the geographic location. The sense of presence, realism, and fidelity were identified as being important factors of a learner's experience within a online virtual environment. These factors became root factors of the fuzzy Human Engagement methodology research.

Mathematical Modeling, such as Regression analysis, which utilizes statistics, is one of the most prevalent methods utilized to build mathematical models; though there are concerns even with this commonly employed modeling method. One such concern, Multicollinearity, can have

serious effects on the estimates of the model parameters and on the general applicability of a final regression model. The fuzzy modeling methodology inherently averted these mathematical modeling concerns. In addition to regression modeling, other types of cognitive architectures were also reviewed, they included:

1. Counterfactual
2. Fitt's Law
3. Classical Test Theory
4. Attribute Hierarchy Methods
5. EPIC
6. Soar
7. ACT-R
8. GOMS
9. Item Response Theory

An extension of a learning theory model labeled the CRESST (National Center for Research on Evaluation, Standards, and Student Testing) model, developed by researchers at the University of California Los Angeles (UCLA), provided the cognitive framework for this research.

In the areas of Psychology and Human Cognitive Sciences, the literature had been dominated by cognitive approaches in interactive multimedia applications. This fuzzy research augmented the CRESST cognitive-based framework of learning with qualitative factors of motivation and self-entitlement. Psychometric scaling enabled researches to quantify qualitative factors. Traditional

Likert and Ordinal scaling methods were the more common methods used to quantify activities such as thinking, memorizing, recalling, and understanding. Psychophysical aspects of human engagement were not overlooked. A few main physiological response measurement methods reviewed or utilized in this research included:

1. Galvanic Skin Response (GSR)
2. Brain Function Analysis (EEG, fMRI, fNIR, and PET/CT Scans)
3. Eye Movement Tracking
4. Heart Rate Monitoring
5. Respiration Monitoring

The physiological response measurements that were chosen to be suitable, and within the scope of this research, were GSR and Heart Rate monitoring.

The Social Sciences contributed to this human engagement research by providing insight into aspects of human interrelationship and interaction. Engagement in the social context addressed the interactive multimedia environment as an extension of the real world (society). Research theory suggests that an individual's cognitive level may be framed by their social context. Social interaction in gaming, especially the MMORPG, is a very prevalent and pertinent aspect of interactive multimedia. These ideas were included in the analysis of the final engagement factor.

The Industrial (IE) and Systems Engineering perspective of standards and metrics in interactive multimedia was more of integration. The integrated approach connected multiple aspects of engagement from various perspectives and included them in an all encompassing framework.

Traditional IE methodologies which included advances in quality philosophy implementation within the manufacturing arena have also been realized in other non-manufacturing areas such as healthcare systems, financial systems, and educational systems; even human engagement modeling within interactive multimedia systems have benefited. Frederic Taylor's Scientific Management as published in 1911 still provides insight for work designers of the 21st century including the foundation of instructional design task analysis.

Human Resource Management ideas helped define engagement with emphasis on human motivation; which was identified a key factor that may impact the level of human engagement. There is relatively little research on the impact of motivation towards learning, motivational impact is a contemporary area of study. Also, there are various management styles that may be utilized in order to better address the needs of the learner such as, Theory X and Theory Y; address human characteristics which transcend cognition and behavior. Multimedia design can have a profound effect on human engagement simply by the way a multimedia design addresses some human resource management characteristics of gamers.

The final area of study, Educational and Training Systems, traditionally defined engagement from the perspective of an identified level of learner behavior, emotion, cognition, participation, and perception of self. Various instruments have been created to monitor qualitative aspects of learning; the Research Assessment Package for Schools (RAPS) Instrument is of particular interest in this research. Educational standards have become of major concern as observed within the last 25 years, since they are viewed as the critical impetus to ensure increased academic achievement.

Chapter 3 Conclusions

The methodological approach of this research focused on empirical observation of subjects interfacing with an interactive multimedia game application, with the intent of defining Human Engagement. Physiological response measurements of Heart Rate and GSR were collected. Once the data was collected, the physiological response data was merged with the Human Perception Cognitive Demands (HPCD) data via the use of Fuzzy Mathematical modeling to produce a quantified output. The HPCD instrument including questions that addressed items such as perceived:

1. Content Understanding: j_1
2. Collaboration/Teamwork: j_2
3. Problem Solving: j_3
4. Affective/Emotional State: j_4
5. Communication: j_5
6. Self Regulation: j_6
7. Realism and Fidelity: j_7
8. Motivation: k_1
9. User Control/Entitlement: k_2
10. Self Regulation Misc.: k_3

HPCD instrument and model validation was conducted utilizing an established instrument.

Chapter 4 Conclusions

When comparing and contrasting Fuzzy Set Theory versus Regression Analysis some major differences include:

1. Fuzzy Modeling allows for the use of SME input while regression relies solely on empirical data.
2. Fuzzy allows for multi-valued qualitative variables versus the binary coding of regression.
3. Factor confounding is more of a concern in the regression since, while not an issue in the Fuzzy Modeling scenario.

Yet, Regression Analysis is widely accepted. Regression is limited to the range of collected data used to derive the regression model. If this data requirement is ignored, extraneous error will be introduced into the model if the model uses data outside of its validated range. Other Regression foundational assumptions should be met prior to use includes:

1. Normally Distributed and Uncorrelated Error
2. Sampling distributions for regressor should be normally distributed
3. All factors in the analysis should exhibit independence

Regression analysis has definite strong and weak points. A Fuzzy methodology was a better fit for this research. A brief description of Fuzzy Sets and some of advantages of Classical Set

theory includes allowable partial set membership. Other aspects of Fuzzy, such as Fuzzy graphical representations called Fuzzy membership functions exist in various forms:

1. S-shaped Sigmoidal
2. Pi-Shaped
3. Triangular-shaped
4. Trapezoidal-shaped

These functions can also be combined to show combinations that adequately represent a Fuzzy set. The s-shaped function was chosen in this research. Overall, Fuzzy models are extremely robust and adaptable to changing environmental needs including those of human engagement modeling.

Chapter 5 Conclusions

The experimental sessions consisted of a small Pilot run and full experimental runs that examined the three levels of interactive multimedia; though of the three levels (types), two media types proved to provide less variability because they were similarly designed (same publisher).

Physiological measures of Heart Rate and GSR were collected while study participants interfaced with the three different interactive multimedia types, SPL, RB6, and COD2.
Out of the two physiological measures, Heart Rate data did not change in participants as greatly as GSR. One reason is that inherently, human physiology is more sensitive to changes in

electrical conductivity; though Heart Rate was the more proven and robust measure discussed throughout the literature. The physiological response measures were only one part of the human engagement factor, the Human Perception and Cognitive Demands constituted the other part.

Analytic Hierarchy Process was the method utilized to derive the factor weightings within the engagement equation. After the weightings were derived the factor level of existence for each factor was assessed through the HPCDI instrument as the participant interfaced the experimental stimulus. Fuzzy Membership Function diagrams were then derived for each factor and a resultant human engagement factor was calculated. Model error analysis was conducted.

An ANOVA analysis was conducted to determine the consistency and accuracy of the HPCDI questions. From the results of the ANOVA, it was determined that the paired positive and negative type questions (for each factor), of the HPCDI, were statistically the same, i.e. they measured the same factor. The fuzzy HPCDI performed as intended. The fuzzy methodology appeared to by a viable alternative.

Chapter 6 Conclusions

Likert and Ordinal Scaling Methods are amongst the most common type of psychometric tools. Traditional usage of questionnaires, such as Likert-based questionnaires, usually happens after a participant's exposure to a media stimulus has occurred. For model validation purposes, a post-

stimulus questionnaire was completed by research participants. Before a particular questionnaire instrument was chosen, the following instruments were reviewed:

1. Witmer and Singer Immersion Tendency Questionnaire (ITQ) and Presence Questionnaire (PQ)
2. Lombard & Ditton Presence Questionnaire
3. Slater-Usoh-Steed (SUS) Presence Questionnaire
4. The Independent Television Commission Sense of Presence Inventory (ITC-SOPI)

Many of the instruments reviewed were used in virtual environment (VE) studies. Presence was a main item of interest for VE researchers and remains an important topic. This idea of Presence most closely addressed the research interests of this human engagement research; however there were various definitions of engagement in other instruments. The ITC-SOPI instrument included sections on Physical Presence, Engagement, Realism/Validity, and Negative Effects; the Engagement section was only considered to validate the Fuzzy human engagement model.

Design points of the ITC-SOPI instrument were:

1. Was originally designed to be administered across a variety of media types including movies and computer games.
2. The Engagement factor of the ITC-SOPI included 13 questions/items.
3. The ITC-SOPI instrumented had been validated on over 600 respondents as of the year 2000.

An ITC-SOPI ANOVA analysis was conducted and revealed that the Engagement question responses were statistically different from each other. The ITC-SOPI did not use a paired positive-negative question approach but asked similar questions with semantic differences. The ITC-SOPI question responses compared and contrasted to those of the fuzzy HPCDI revealed that the HPCDI contained less variability than that of the ITC-SOPI, hence the HPCDI did not contain any more error than the Likert-based ITC-SOPI; in essence this research's Fuzzy human engagement modeling methodology was valid and viable.

Future Research Points of Interest

It is hypothesized that more extensive research on the assigning of AHP factor weightings, would progress this research to the next level. As theory is developed, expert knowledge could easily be incorporated into the existing model framework. Expert, SME insight would be beneficial to this research by providing direction and defining trending behavior of new research on factors that impact Human Engagement in interactive multimedia applications.

Advances in physiological response measurement, should also increase the fidelity of this research. Many of the nascent technologies in this research are relatively relegated to a laboratory environment due to factors such as cost and reliability. Further development and research should attenuate these limiting factors.

Also, true MMORPG environmental research would increase the complexity of this research. The social interaction of humans on teams with 10 or even 100 members was not addressed directly, by this research; however, the incremental components of interactive multimedia addressed in this research should provide an established foundation for further study.

Human Engagement, learning efficiency, and training may be realized according to this research. Standards are the beginning of meaningful benchmarking and continuous improvement efforts. Fuzzy methodologies can provide robust and viable options in the present and future research of interactive multimedia environments as continue to become a common part of human life.

APPENDIX A: UCF IRB APPROVAL LETTER

University of Central Florida Institutional Review Board
Office of Research & Commercialization
12201 Research Parkway, Suite 501
Orlando, Florida 32826-3246
Telephone: 407-823-2901, 407-882-2012 or 407-882-2276
www.research.ucf.edu/compliance/irb.html

Notice of Expedited Initial Review and Approval

From : **UCF Institutional Review Board**
FWA00000351, Exp. 10/8/11, IRB00001138

To : **Chandre Butler**

Date : **May 07, 2009**

IRB Number: **SBE-09-06242**

Study Title: **THE DEVELOPMENT OF A HUMAN-CENTRIC FUZZY MATHEMATICAL MEASURE OF HUMAN ENGAGEMENT IN INTERACTIVE MULTIMEDIA SYSTEMS AND APPLICATIONS**

Dear Researcher:

Your research protocol noted above was approved by **expedited** review by the UCF IRB Vice-chair on 5/7/2009. **The expiration date is 5/6/2010.** Your study was determined to be minimal risk for human subjects and expeditable per federal regulations, 45 CFR 46.110. The categories for which this study qualifies as expeditable research are as follows:

6. Collection of data from voice, video, digital, or image recordings made for research purposes.

7. Research on individual or group characteristics or behavior (including, but not limited to, research on perception, cognition, motivation, identity, language, communication, cultural beliefs or practices, and social behavior) or research employing survey, interview, oral history, focus group, program evaluation, human factors evaluation, or quality assurance methodologies.

The IRB has approved a **consent procedure which requires participants to sign consent forms.** Use of the approved, stamped consent document(s) is required. Only approved investigators (or other approved key study personnel) may solicit consent for research participation. Subjects or their representatives must receive a copy of the consent form(s).

All data, which may include signed consent form documents, must be retained in a locked file cabinet for a minimum of three years (six if HIPAA applies) past the completion of this research. Any links to the identification of participants should be maintained on a password-protected computer if electronic information is used. Additional requirements may be imposed by your funding agency, your department, or other entities. Access to data is limited to authorized individuals listed as key study personnel.

To continue this research beyond the expiration date, a Continuing Review Form must be submitted 2 – 4 weeks prior to the expiration date. Advise the IRB if you receive a subpoena for the release of this information, or if a breach of confidentiality occurs. Also report any unanticipated problems or serious adverse events (within 5 working days). Do not make changes to the protocol methodology or consent form before obtaining IRB approval. Changes can be submitted for IRB review using the Addendum/Modification Request Form. An Addendum/Modification Request Form **cannot** be used to extend the approval period of a study. All forms may be completed and submitted online at http://iris.research.ucf.edu .

Failure to provide a continuing review report could lead to study suspension, a loss of funding and/or publication possibilities, or reporting of noncompliance to sponsors or funding agencies. The IRB maintains the authority under 45 CFR 46.110(e) to observe or have a third party observe the consent process and the research.

On behalf of Tracy Dietz, Ph.D., UCF IRB Chair, this letter is signed by:

Signature applied by Joanne Muratori on 05/07/2009 08:51:13 AM EDT

IRB Coordinator

APPENDIX B: FUZZY MATHEMATICAL MODELING OF THE HUMAN ENGAGEMENT AHP (FACTOR WEIGHTINGS) SURVEY (COMPLETED)

FUZZY MATHEMATICAL MODELING OF HUMAN ENGAGEMENT

SURVEY

Topic: Survey information for Fuzzy Modeling of Human Engagement in Interactive Multimedia Applications. Factor weights will be derived from this information.

SME/Preparer: RE

Date: 10/09

• **Survey Purpose**

What is the significance physiological and psychosocial factors and their impact on Human Engagement in Interactive Multimedia Applications? By quantifying qualitative data into an equation format we can obtain repeatable and measurable results that may be utilized by system administration to aide in decision-making activities through a process known as Analytic Hierarchy Process (AHP). AHP can be used to determine factor relative weighting and significance by assessing pair-wise comparisons.

• **Instructions**

1. Please answer questions A and B as they relate to the question being asked.
2. Section Length: 22 questions and Estimated Completion Time: 30 min.

Section 1: Physiological Factor Weighting Calculation

1. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Heart Rate h_1"

vs.

"GSR h_4"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

Section 2: Human Perception and Cognitive Demands Weighting Calculation

1. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Collaboration/Teamwork j_2"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

2. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Problem Solving j_3"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

3. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Affective/Emotional State j_4"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

4. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Communication j_5"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

5. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Self Regulation (Motivation and User Control/Entitlement) j_6"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

6. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Content Understanding j_1"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

7. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Collaboration/Teamwork j_2"

vs.

"Problem Solving j_3"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

8. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Collaboration/Teamwork j_2"

vs.

"Affective/Emotional State j_4"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

9. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Collaboration/Teamwork j_2"

vs.

"Communication j_5"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

10. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Collaboration/Teamwork j_2"

vs.

"Self Regulation (Motivation and User Control/Entitlement) j_6"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

11. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Collaboration/Teamwork j_2"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

12. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Problem Solving j_3"

vs.

"Affective/Emotional State j_4"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

13. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Problem Solving j_3"

vs.

"Communication j_5"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

14. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Problem Solving j_3"

vs.

"Self Regulation (Motivation and User Control/Entitlement) j_6"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

15. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Problem Solving j_3"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

16. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Affective/Emotional State j_4"

vs.

"Communication j_5"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

17. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Affective/Emotional State j_4"

vs.

"Self Regulation (Motivation and User Control/Entitlement) j_6"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

18. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Affective/Emotional State j_4"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

19. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Communication j_5"

vs.

"Self Regulation (Motivation and User Control/Entitlement) j_6"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

20. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Communication j_5"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

21. Which factor of the following pair-wise comparisons is (if perceived to be) a more significant:

a. **POSITIVE** influence or indicator of the level of Human Engagement?

b. To what degree of significance exists based on the rating scale below?

A. "Self Regulation (Motivation and User Control/Entitlement) j_6"

vs.

"Realism and Fidelity j_7"

B. Rating (Indicate Degree of Relative Significance Here 1 - 9):

Positive _____

Rating Scale

Degree of Relative Significance	Definition
1	Equal Significance
2	Intermediate Between 1 and 3
3	Weak Significance (Of One Over Other)
4	Intermediate Between 3 and 5
5	Strong Significance (Of One Over Other)
6	Intermediate Between 5 and 7
7	Demonstrated Significance Over the Other
8	Intermediate Between 7 and 9
9	Absolute Significance

Top Level Resultant Table

AHP	G_1	G_2
G_1	1	1
G_2		1

Section 1 Resultant Score Table

AHP	h_1	h_4
h_1	1	5
h_4		1

Section 2 Resultant Score Table

AHP	j_1	j_2	j_3	j_4	j_5	j_6	j_7
j_1	1	7	1	3	5	3	3
j_2		1	7	8	3	8	8
j_3			1	3	5	3	4
j_4				1	9	1	3
j_5					1	8	8
j_6						1	2
j_7							1

Section 3 Resultant Score Table

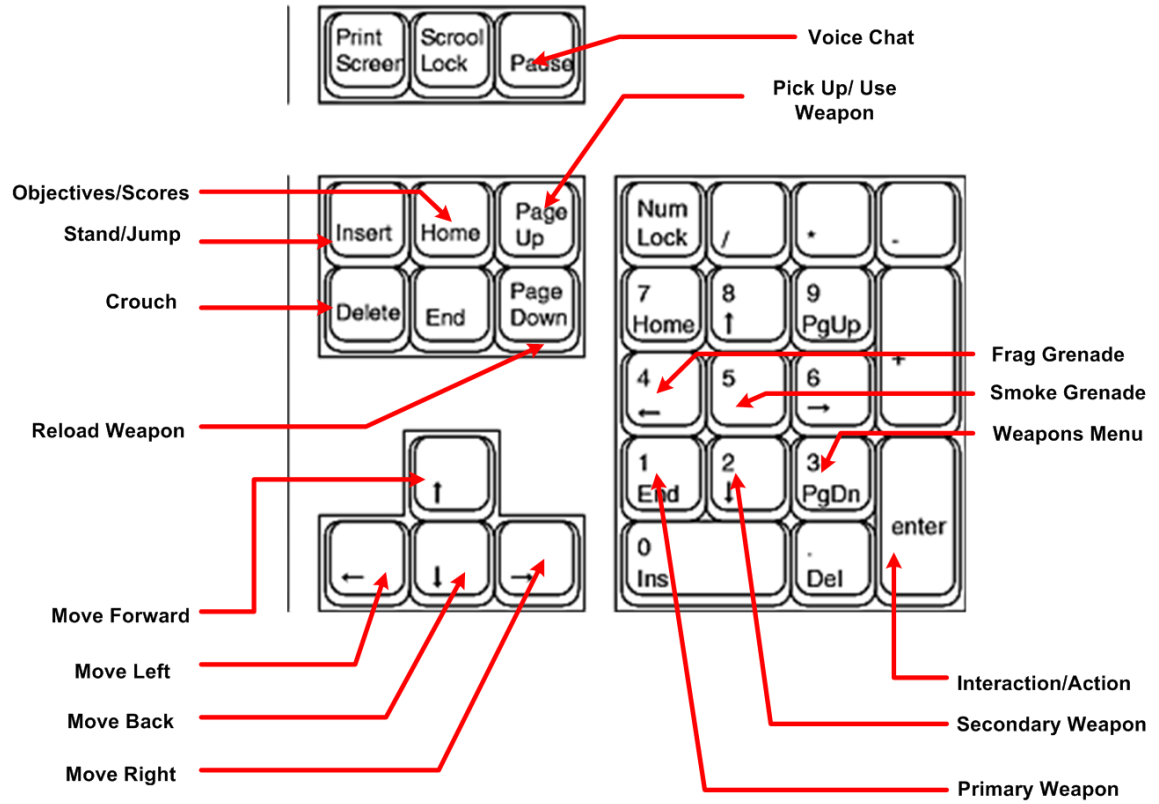
AHP	k_1	k_2	k_3
k_1	1	1	1
k_2		1	1
k_3			1

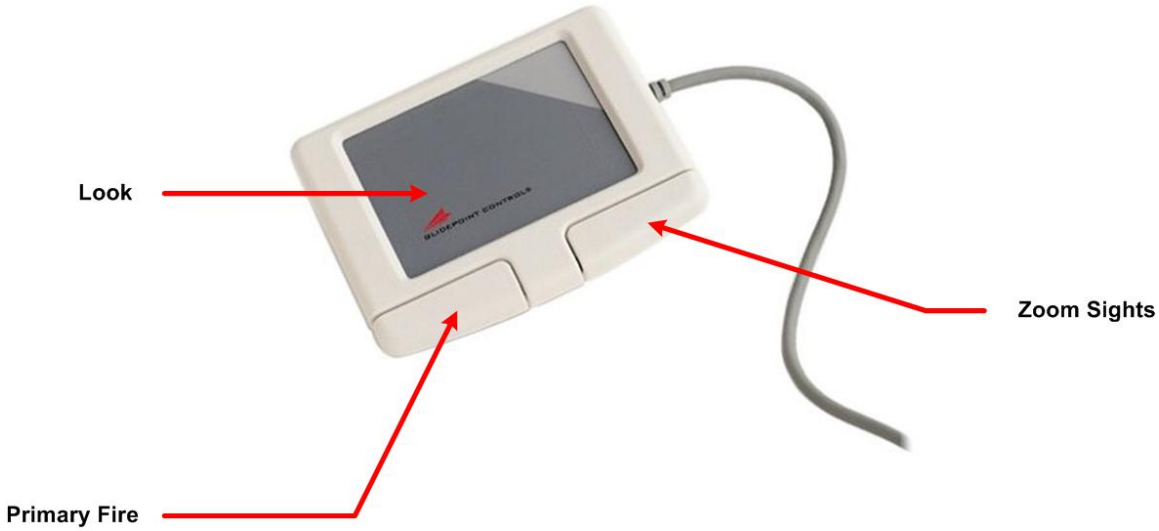
Analysis Software:

1. Expert Choice Trial 11.5.1472
2. Copyright© 1982-2009 Expert Choice, Inc. All rights reserved.
3. Database Version: 3.04
4. Limitations:
    a. Maximum Number of Participants – 3
    b. Maximum Number of Nodes per Cluster – 9
    c. Maximum Number of Alternatives - 8

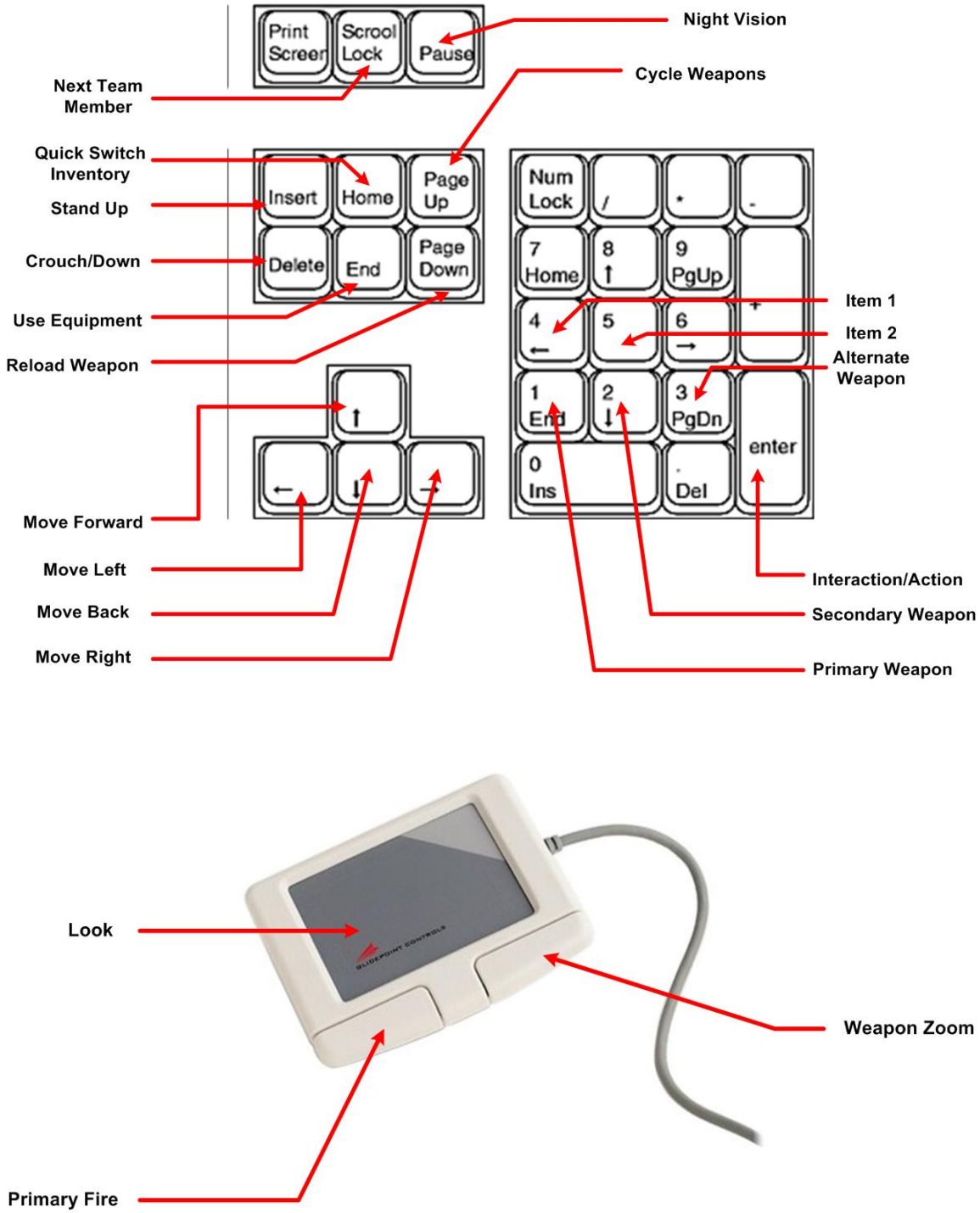
APPENDIX C: GAMING STIMULUS DOCUMENTS

Call of Duty 2 (COD2) Keyboard and Trackpad Mapping

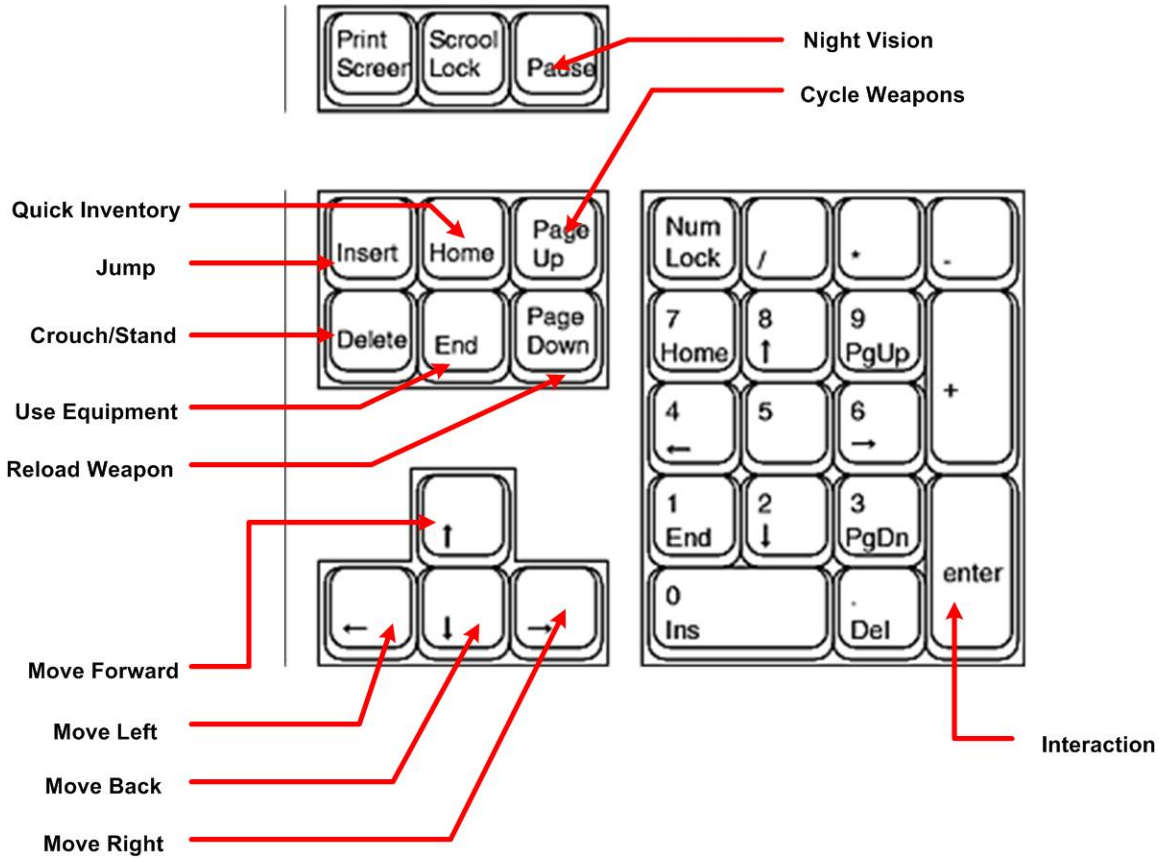


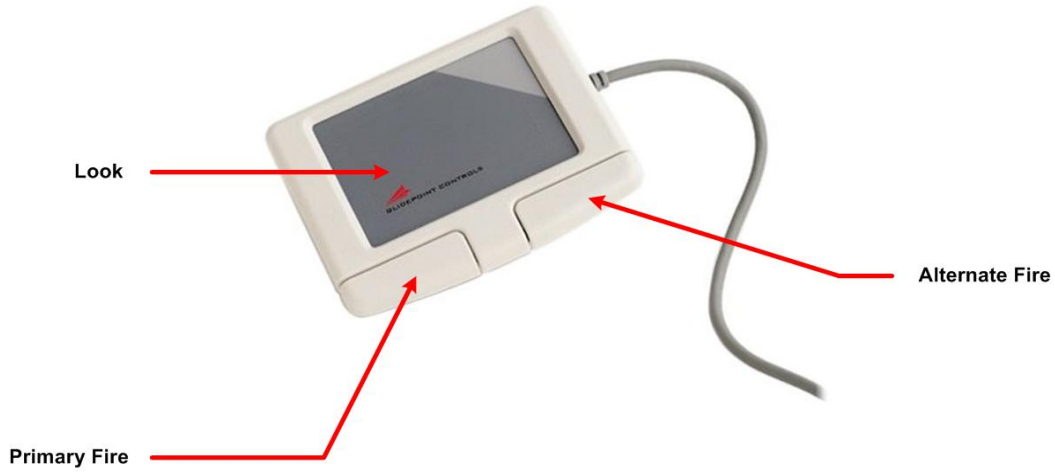


Rainbow 6 (RB6) Keyboard and Trackpad Mapping



Splinter Cell (Splinter) Keyboard and Trackpad Mapping





Game Stimulus Task Analysis/Intro

Call of Duty 2 (COD 2) Task Analysis

Mode: Multiplayer

Game Mode: Headquarters/Mission

Description: Headquarters is a team-based objective mode with respawning. A location in the map is randomly selected from a list of different places, and each team fights over that spot (it is a flashing radio indicator on the map) to hold it and set up their headquarters there. Once a team has set up a headquarters, they must defend it for 45 seconds. If they succeed, then they score major points, everyone respawns and they have to do it again. If they fail, then the attacking team scores points, everyone respawns, a new random location is chosen, and each team fights to set up their headquarters again. The teams respawn together simultaneously.

Mission is a multiplayer aspect of the main game. Players are part of a squad that carries out predefined missions. Within each mission each player has a specific role that must be followed or the game will not continue.

High Level Game Operations and Actions:

1. Goal: Be the first to arrive at the indicated headquarters site and defend it.
2. Mission Type/Activity: Search and Defend

Mid Level Game Operations Actions:

1. Attacking /Being Attacked – Team players will be expected to engage the opposing team and defend against attacks from the opposing team.
2. Pursuing – Team players are expected to search and pursue headquarter spots and opposing team members.

3. Holding – Team players may expect to wait and be attentive to possible future attacks or plan to attack via a team strategy within the game.

Low Level Game Operations and Actions:

1. Team members will be allowed to communicate via Voice chat (see keyboard and touchpad mapping diagrams).
2. Player movements and actions will be controlled via keyboard and touchpad

Research Notes:

- HPCDI Data Points: 1 min. intervals
- Live Team Chat Functions
- Heart Rate Monitor: Utilized
- GSR Device: Utilized
- Integrated Headset/Mic: Utilized
- HPCDI Questions (9 questions): Questions will be asked during game-play, a verbal response will be expected.

References:

http://www.gamespy.com/pc/call-of-duty/6561p1.html

Rainbow 6 3 “Raven Shield” (RB6) Task Analysis

Mode: Single-Player Squad Lead

Game Mode: Campaign

Description:

Operation: Stolen Flame, November 30, 2005 @ 2300, Amuay, Venezuela. Terrorists have occupied an oil refinery in Amuay. They're demanding that Peja Sicic, a high-ranking official for the Axis powers in WWII, not be deported. If he is deported, they threaten to blow up the refinery. The building is composed of only two floors, and your enemies are fairly weak.

High Level Game Operations and Actions:

1. Goal: Eliminate all Terrorists
2. Mission Type/Activity: Search and Eliminate Terrorists

Mid Level Game Operations Actions:

1. Attacking /Being Attacked – Team players will be expected to engage terrorists and defend against attacks from terrorists.
2. Pursuing – Team players are expected to search and pursue Terrorists by searching rooms and areas.
3. Holding – Team players may expect to wait and be attentive to possible future attacks or plan to attack via a team strategy within the game.

Low Level Game Operations and Actions:

1. Players on same team will be allowed to communicate via in-game pre-scripted controls.
2. Player movements and actions will be controlled via keyboard and touchpad.
3. Doors and ladders may be interacted with (Doors opened and ladders climbed) via the actions on the keyboard.

Research Notes:

- HPCDI Data Points: 1 min. intervals
- Heart Rate Monitor: Utilized
- GSR Device: Utilized
- Integrated Headset/Mic: Utilized
- HPCDI Questions (9 questions): Questions will be asked during game-play, a verbal response will be expected.

References:

http://www.gamefaqs.com/computer/doswin/file/556765/27514

Splinter Cell "Chaos Theory" Task Analysis

Mode: Single-Player

Game Mode: Solo

Description: You begin this mission on the beach below the lighthouse and the series of caves that run underneath it. There isn't anything to bother you save for the bats; there aren't any enemies here, so feel free to run around, figure out your controls, learn how to use your weapons, and so on. When you're ready to move out, find the rocky path leading up from the beach and follow it into the caves. You'll need to press through a tight corridor, as well as crawl through a crawlspace, but eventually you'll reach the first large cave, where a secondary objective will pop up, regarding the guerillas and their suspiciously sophisticated equipment. When you jump up into the cave with the suspended wooden bridge, a pair of soldiers will appear from across the way and start patrolling. They don't suspect your presence - yet - so be careful to avoid alerting them. If you wait long enough, one will head back along the path they came through, leaving the other one for you to eliminate. If you creep up stealthily enough, you'll be able to grab him and interrogate him, but he doesn't have anything tremendously useful to say.

Get used to waiting in the darkness for guards to pass by, then sneaking up and grabbing them.

High Level Game Operations and Actions:

1. Goal: Stealthily eliminate enemies if needed. Enemies can be interrogated for information.
2. Mission Type/Activity: Search and Rescue. Execute in-game objectives.
    a. Recover or Destroy Information About The Masse Kernels
    b. Rescue character named Morgenholt
    c. Eliminate Hugo Lacerda
    d. Scan the SSCC Bar Code of the Delivered Crates

Mid Level Game Operations Actions:

1. Attacking /Being Attacked – Players will be expected to engage enemies and defend against attacks from enemies. Though a stealth approach may be required in order to meet the in game objectives.
2. Pursuing – Players are expected to search and pursue enemies and objectives by searching rooms and areas.
3. Holding –Players may expect to wait and be attentive to possible future attacks or plan to attack via a strategy within the game.

Low Level Game Operations and Actions:

1. Player movements and actions will be controlled via keyboard and touchpad.
2. Doors and ladders may be interacted with (Doors opened and ladders climbed) via the actions on the keyboard.
3. Disabled or killed enemies may be moved or hidden.

Research Notes:

- HPCDI Data Points: 1 min. intervals
- Heart Rate Monitor: Utilized
- GSR Device: Utilized
- Integrated Headset/Mic: Utilized
- HPCDI Questions (9 questions): Questions will be asked during game-play, a verbal response will be expected.

References:

http://www.gamespot.com/features/6121234/p-8.html

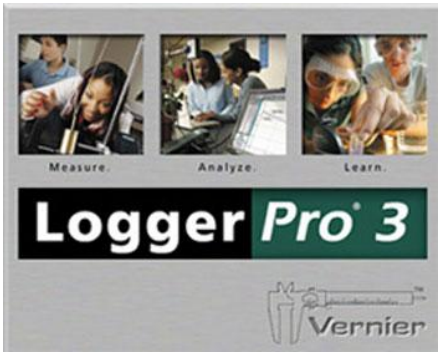
APPENDIX D: EXPERIMENTAL EQUIPMENT

QUBIT Systems Inc. Equipment

GSR Sensor The S220 Galvanic Skin Response (GSR) Sensor measures the psycho-galvanic reflex. This reflex generates a change in skin conductivity during periods of stress, excitement or shock. The GSR sensor monitors skin conductivity between two reusable electrodes attached to 2 fingers of one hand. While the subject is at rest, a steady background signal will be monitored by C901 Logger Pro software on the computer screen. It is also possible to obtain an audible signal. The subject may then be stimulated in different ways and the degree of stimulation measured graphically.

Wireless Heart Rate Monitor The S182 Wireless Exercise Heart Rate Monitor is ideal for determining the heart rate of individuals. Using this sensor, a subject's heart rate can be monitored before, during and after exercise. The Exercise Heart Rate Monitor consists of a wireless transmitter belt and a receiver module designed to plug into a LabPro Interface. The transmitter belt senses the electrical signals generated by the heart, much like an EKG. For each heartbeat detected, a signal is transmitted to the receiver module, and a heart rate is determined. The voltage signal is transmitted to the computer via the interface and may be displayed as Beats per Minute (BPM) by C901 Logger Pro 3 software.

LabPro Data Acquisition Interface The LabPro Interface may be used with a PC or Mac computer, a Palm Hand-Held running C915 Data Pro for Palm software or as a stand-alone data logger when configured with C901 Logger Pro software (sold separately).



Logger Pro 3 Logger Pro Software for both PC and Mac computers, integrates real-time graphing, powerful analytical functions, integrated calibration procedures and data storage into one powerful program.

Information retrieved from - http://www.qubitsystems.com

APPENDIX E: HUMAN PERCEPTION AND COGNITIVE DEMANDS INVENTORY (HPCDI)

HPCDI Instrument (Human Perception & Cognitive Demands)

Created by: Chandre Butler

Description: The HPCDI was created to be used as an aide in the determining of the level of engagement of participants in interactive multimedia environments. The Center for Research on Evaluation, Standards, & Student Testing (CRESST) framework and Rochester Assessment Package for Schools (RAPS) inventory are the foundation of the instrument. HPCDI is to be administered during stimulus exposure.

	Statement/Question	CRESST (Cognitive Demand)	RAPS-SM (Domain/Sub)	Other (Sub-factor)
1	The mission is **hard.**	Problem Solving (j_3)	Engagement (Ongoing)	-
2	The mission is easy.	Problem Solving (j_3)	Engagement (Ongoing)	-
3	You are **not** prepared for the mission.	Content Understanding (j_1)	Engagement (Ongoing)	-
4	You are prepared for the mission.	Content Understanding (j_1)	Engagement (Ongoing)	-
5	You can**not** complete the mission if you work hard.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
6	You can complete the mission if you work hard.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
7	You can**not** complete the mission because the team will **not** help you.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
8	You can complete the mission because the team will help you.	Self-Regulation (k_3)	Beliefs About Self (Competence)	-
9	You feel **bad** when you think	Self-Regulation (k_3)	Beliefs About	-

	about how you are performing.		Self (Relatedness)	
10	You feel good when you think about how you are performing.	Self-Regulation (k_3)	Beliefs About Self (Relatedness)	-
11	You feel **alone** in the game.	Collaboration or Teamwork (j_2)	Beliefs About Self (Relatedness)	-
12	You feel you are part of the team.	Collaboration or Teamwork (j_2)	Beliefs About Self (Relatedness)	-
13	The team **ignores** you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
14	The team listens to you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
15	The squad leader does **not** have clear expectations for you on the team.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
16	The squad leader has clear expectations for you on the team.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
17	The squad leader does **not** like the other team members more than you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
18	The squad leader likes the other team members more than you.	Collaboration or Teamwork (j_2)	Interpersonal Support	-
19	Team members do **not** tell you when they need help.	Communication (j_5)	Interpersonal Support	-
20	Team members tell you when they need help.	Communication (j_5)	Interpersonal Support	-
21	It is **hard** to talk to the team about the mission.	Communication (j_5)	Interpersonal Support	-
22	It is easy to talk the team about the mission.	Communication (j_5)	Interpersonal Support	-
23	You do **not** want to continue the mission because it is boring.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
24	You want to continue the mission because it is	-	Beliefs About Self (Autonomy)	Motivation (k_1)

	interesting.			
25	**Not** knowing how well you are doing makes you want to quit.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
26	Knowing how well you are doing keeps you playing.	-	Beliefs About Self (Autonomy)	Motivation (k_1)
27	The graphics in the game are **not** good.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
28	The graphics in the game are good.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
29	You do **not** feel like you are part of the game.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
30	You feel like you are part of the game.	-	Engagement (Challenge)	Realism and Fidelity (j_7)
31	You do **not** feel it is your responsibility to complete the mission.	-	Beliefs About Self (Competence)	User Control/Entitlement (k_2)
32	You feel it is your responsibility to complete the mission.	-	Beliefs About Self (Competence)	User Control/Entitlement (k_2)
33	You do **not** feel you have total control over the mission.	-	Beliefs About Self (Competence)	User Control/Entitlement (k_2)
34	You feel you have total control over the mission.	-	Beliefs About Self (Competence)	User Control/Entitlement (k_2)
35	You do **not** feel excited.	-	Beliefs About Self (Relatedness)	Affective/Emotional State (j_4)
36	You feel excited.	-	Beliefs About Self (Relatedness)	Affective/Emotional State (j_4)
37	You do **not** like the game.	-	Beliefs About Self (Relatedness)	Affective/Emotional State (j_4)
38	You like the game.	-	Beliefs About Self (Relatedness)	Affective/Emotional State (j_4)

APPENDIX F: ITC-SOPI INVENTORY (ENGAGEMENT)

Please indicate HOW MUCH YOU AGREE OR DISAGREE with each of the following statements by circling just ONE of the numbers using the 5-point scale below.

(Strongly disagree) (Disagree) (Neither agree nor disagree) (Agree) (Strongly agree)
1 2 3 4 5

Part A

1. I felt sad that my experience was over 1 2 3 4 5

3. I had a sense that I had returned from a journey..... 1 2 3 4 5

4. I would have liked the experience to continue 1 2 3 4 5

5. I vividly remember some parts of the experience..... 1 2 3 4 5

6. I'd recommend the experience to my friends. 1 2 3 4 5

Part B

1. I felt myself being 'drawn in'. 1 2 3 4 5

2. I felt involved (in the displayed environment). 1 2 3 4 5

3. I lost track of time..... 1 2 3 4 5

8. I enjoyed myself. 1 2 3 4 5

16. My experience was intense..... 1 2 3 4 5

17. I paid more attention to the displayed environment than I did to my own thoughts (e.g., personal preoccupations, daydreams etc.). 1 2 3 4 5

30. I responded emotionally 1 2 3 4 5

32. The content appealed to me. 1 2 3 4 5

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