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VIRTUAL INTERACTIONS WITH REAL-AGENTS FOR SUSTAINABLE NATURAL RESOURCE MANAGEMENT

by

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A thesis submitted in partial fulfillment of the requirements
for the degree of Master of Science
in the Department of Civil, Environmental and Construction Engineering
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Major Professor: Kaveh Madani
ABSTRACT

Common pool resource management systems are complex to manage due to the absence of a clear understanding of the effects of users’ behavioral characteristics. Non-cooperative decision making based on individual rationality (as opposed to group rationality) and a tendency to free ride due to lack of trust and information about other users’ behavior creates externalities and can lead to tragedy of the commons without intervention by a regulator. Nevertheless, even regulatory institutions often fail to sustain natural common pool resources in the absence of clear understanding of the responses of multiple heterogeneous decision makers to different regulation schemes. While modeling can help with our understanding of complex coupled human-natural systems, past research has not been able to realistically simulate these systems for two major limitations: 1) lack of computational capacity and proper mathematical models for solving distributed systems with self-optimizing agents; and 2) lack of enough information about users’ characteristics in common pool resource systems due to absence of reliable monitoring information. Recently, different studies have tried to address the first limitation by developing agent-based models, which can be appropriately handled with today’s computational capacity. While these models are more realistic than the social planner’s models which have been traditionally used in the field, they normally rely on different heuristics for characterizing users’ behavior and incorporating heterogeneity. This work is a step-forward in addressing the second limitation, suggesting an efficient method for collecting information on diverse behavioral characteristics of real agents for incorporation in distributed agent-based models. Gaming in interactive virtual environments is suggested as a reliable method for understanding different variables that promote sustainable resource use through observation of decision making and
behavior of the resource system beneficiaries under various institutional frameworks and policies. A review of educational or "serious" games for environmental management was undertaken to determine an appropriate game for collecting information on real-agents and also to investigate the state of environmental management games and their potential as an educational tool. A web-based groundwater sharing simulation game—Irrigania—was selected to analyze the behavior of real agents under different common pool resource management institutions. Participants included graduate and undergraduate students from the University of Central Florida and Lund University. Information was collected on participants’ resource use, behavior and mindset under different institutional settings through observation and discussion with participants. Preliminary use of water resources gaming suggests communication, cooperation, information disclosure, trust, credibility and social learning between beneficiaries as factors promoting a shift towards sustainable resource use. Additionally, Irrigania was determined to be an effective tool for complementing traditional lecture-based teaching of complex concepts related to sustainable natural resource management. The different behavioral groups identified in the study can be used for improved simulation of multi-agent groundwater management systems.
I dedicate this master thesis work to my family and friends. To my loving parents Vanessa, Chris, Stuart and Deb, your support and encouragement has always motivated me to strive for excellence and never give up. You have always been there for me, believed in me, sacrificed for me and are the reason I have made it to this point. I love you all so much and I am forever grateful for all you have done.

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To the rest of my family and friends, I thank you for your love and support. Through all the difficult times you have always been there to help me out and cheer me up. I hope that now this thesis is finished I will once again be able see all of you again.
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I also thank Jan Seibert and Marc Vis at the University of Zurich for allowing us to use Irrigania, Tom Gleeson at McGill University for encouraging us to use Irrigania, Kippy Ahluwalia and Summer Carlson for their help researching and the graduate and undergraduate
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CHAPTER 1. INTRODUCTION

1.1 Background of the Problem

Sustainable management of common pool resource (CPR) systems has been a focus of research for the last three decades (Agrawal, 2003). Increasing population, higher effluence, and climate change have perpetuated the strain on water resources, essential to the social, economical and environmental prosperity of humans. Natural resources management is becoming more complicated as the number of consumers grows and requirements put upon environmental and economic factors increase. The success of sustainable development will rely not only on understanding the effects that different institutions have on CPRs, the externalities associated with them and the behaviors of their beneficiaries, but also on formulating a theoretical framework for pursuing sustainable management.

In recent years, agent-based modeling (ABM) has become the popular choice for modeling human and natural systems due to its ability to capture emergent phenomena, provide a natural description of a system and allows for flexibility (Bonabeau, 2002; Bousquest, Lifran, Tidball, Thoyer, & Antona, 2001). In ABM, the system consists of autonomous decision making entities called agents that independently make decisions based on a set of rules (Bonabeau, 2002). ABM correlates well with CPR management because it too consists of a network of interacting agents, exhibits a dynamic aggregate behavior caused by interactions between agents, and develops aggregate behavior which can be described without knowledge of the behavior of the individual agents (Holland & Miller, 1991; Deadman, Schlager, & Gimblett, 2000).
Modeling agents in a natural system can be undertaken to determine the effects of institutional arrangements and management techniques for the purpose of policy development (Bousquest, Lifran, Tidball, Thoyer, & Antona, 2001). However, it is assumed that agents behavior and interactions can be plausibly modeled with enough detail to serve the intended purpose, but this is not always the case. ABMs normally rely on different heuristics for characterizing users' behavior and incorporating heterogeneity to account for the complex human-natural system dynamics that inherently involve human agents that potentially exhibit irrational behavior, subjective choices and complex psychology (Bonabeau, 2002). Stakeholders bring with them differing knowledge in regard to the empirical context, laws and institutions, and beliefs, myths, and ideas that initiate policy conflicts that arise from the disparity between stakeholders' perceptions and understanding of the problems and possible solutions (Adams, Brockington, Dyson, & Vira, 2003). However, these complex variables depend on the ambiguous nature of the designing expert (D'Aquino, Le Page, Bousquet, & Bah, 2003). The result is that policies are developed, which often assume that the actors involved have a complete understanding of the underlying problem, while in reality they may not. In fact, the assumptions, knowledge and understanding that define the problem in the first place are many times uncertain and challenged by the various actors (Adams, Brockington, Dyson, & Vira, 2003). Using data from real agents through the use of a virtual environment, may provide a more accurate method for understanding different variables that promote sustainable resource use. One of the limitations that exist in modeling complex coupled human-natural systems today is the lack of information regarding users' characteristics in CPR systems due to the absence of reliable monitoring information (Janssen & Ostrom, 2006). Collecting information from real agents offers an efficient method that can be incorporated in distributed agent-based models.
In addition to modeling natural resources, the demands on professionals in the natural resource management industry are also evolving, requiring engineers to work with stakeholders regularly, which requires good interpersonal skills, communication abilities and team dynamics (Deshpande & Huang, 2011). Due to uncertainties from dynamic systems, human influences and climate change, future engineers will require higher-order, reflective, metacognitive and critical thinking skills to conceptualize dynamic processes (Thompson, Ngambeki, Troch, Sivapalan, & Evangelou, 2012). The result is a demand for engineers with developed intangible skills and an interdisciplinary and systems approach to problem-solving (Hoekstra, 2012). A recognized need, therefore, is to teach these concepts and skills to today’s students studying natural resource management to prepare them for future success as professionals.

In recent years, there has been a push by researchers and educators to transition from purely traditional transmission processes (lectures, reading and structured problem sets) to those that include student-centered learning (constructivism learning orientation) (Hoekstra, 2012; Beavis & Beckmann, 2012; Barbalios, Ioannidou, Tzionas, & Paraskeuopoulos, 2013; Thompson, Ngambeki, Troch, Sivapalan, & Evangelou, 2012). Student-centered learning is supported by research as it has been found to advance multiple science learning goals, including motivation to learn science, conceptual understanding, science process skills, understanding of the nature of science, scientific discourse and argumentation, and identification with science and science learning (Honey & Hilton, 2010). The goal is to produce students who have a “deep” understanding of knowledge, able to connect and apply new ideas with prior knowledge, as opposed to memorization or “pass the test” learning (Beavis & Beckmann, 2012; Biggs, 1999). Unfortunately, the introduction of social and interdisciplinary dimensions of natural resource
management that promote these ideas often fall short in most curricula at the university level (Hoekstra, 2012; King, O'Donnell, & Caylor, 2012).

Serious games (SGs) are an increasingly popular tool used for education, training and stakeholder negotiations (Abt, 1987; Michael & Chen, 2005; Susi, Johannesson, & Backlund, 2007) that may have the potential to serve as a platform for both information collection of real agents in a virtual environment and to teach complex ideas about natural resource management. To determine the effectiveness of this method, a state of the art review of environmental management SGs was developed and one of the games—Irrigania—was implemented in undergraduate and graduate classes at the University of Central Florida and Lund University.

The remaining chapters of this thesis are as follows. In Chapter 2, a literature review introduces GBL, SGs, learning principles, and learning orientations. This chapter also presents the research methodology and rationale for conducting a review of environmental management serious games and a discussion about the findings. Chapter 3 presents a background on CPRs and institutional arrangements associated with CPR management. Next, the serious game Irrigania is introduced as a platform for CPR data collection and education. The methodology, participants and analysis techniques for Irrigania are then explained. The last section of chapter 3 presents the results of implementing Irrigania and a comparison within and between the three groups of participants. Finally, chapter 4 addresses the research questions within the context of the research and addresses limitations of the study and future work.

1.2 Justification of the Study

The importance of this study is twofold: (1) to investigate data collected from users’ decision making and behavioral characteristics and its incorporation in distributed agent-based models
and (2) in its ability to determine the feasibility of implementing a serious game for teaching concepts and skills related to natural resource management and the learning outcomes that can be attained by its use. Although the focus of this study primarily addresses applications of online gaming for CPR education, management and data collection the arguments for this specific area are not unique and may be applicable to related disciplines.

1.3 Research Objectives

The main objectives of this research are to answer the following questions:

Research Question 1: What uses can collecting information on real agents have on modeling agents' behavior in water sharing problems?

Research Question 2: How similar are the responses from actors in a virtual CPR environment to those in reality?

Research Question 3: What effects on behavior and decision making do different institutional arrangements and policies have on sustainable resource use in a virtual CPR system?

Research Question 4: What learning outcomes can be developed for CPR management using student-centered learning tools as a complement to traditional transmission learning?

Research Question 5: How do different institutional arrangements in a virtual environment affect participants’ learning outcomes?
CHAPTER 2. ENVIRONMENTAL MANAGEMENT GAME REVIEW

2.1 Introduction

Often when we think of video games (VGs) and gamers, it is usually games such as World of Warcraft, Call of Duty or Star Wars that come to mind. These games contain graphics, storylines, and multi-player capabilities that players find entertaining and engaging, and this is one of the main reasons gamers spend so much of their free-time playing these type of games. In addition to this $66 billion global video game industry (DFC Intelligence, 2013), there is also a growing branch of digital educational games that proponents believe provide an effective learning medium to which today’s students are more receptive. These students, who were the first generation to grow up with VGs, in addition to other digital technology including internet, computers, MP3 players, and smartphones, have been coined the Net-generation, Digital-generation or digital natives (Prensky, 2001).

The title, digital natives, is used to refer to those who have grown up their entire lives with such technologies, thus making them natives of the digital world. Prensky (2001) believes that digital natives think and process information differently than previous generations because of the pervasiveness of exposure to technology that is characteristic of today's youth. Today's youth are connected with each other almost constantly through smartphones and computers and communicate by calls, texts, video messaging, emails, social media messaging, and more. They also spend their time differently too. In 2009 it was estimated that total media exposure among youth ages 8-18 was 10:45 hours on average; an increase from 8:33 hours in 2004 and 7:29 hours in 1999 (Rideout, Foehr, & Roberts, 2010). Video gaming, specifically, increased to an average of 73 minutes per day in 2009, a marked increase from 49 minutes in 2004 and 26 minutes in
1999 (Rideout, Foehr, & Roberts, 2010). The demographic of gamers may also be surprising; it includes more than just young children and teenage boys. The gender distribution of games is 47% female and 53% male and the average age of gamers is 30 years old (Entertainment Software Association, 2012).

Although games and simulations developed for teaching purposes have been around since the mid-twentieth century, they are still not widely used in K-12 or higher education. Games developed for educational purposes or "serious games" have experienced increased attention in the past decade as advances in technology have made electronic media more accessible and digital games more powerful. Computer graphics and realistic simulations can allow students to role-play in environments that would otherwise be impossible to replicate in a classroom (Kirriemuir & McFarlane, 2004), such as an astronaut in space or a doctor in the emergency room.

An area where serious games (SGs) are thought to have a particularly high potential for overcoming deficiencies of traditional lecture-driven classes are in science, technology, engineering and math (STEM) curricula (Levine M. H., 2011; Mayo, 2007). Reasons that students claim to leave STEM programs include either loss of interest in the curriculum, loss of academic self-confidence resulting from a competitive environment (Seymour & Hewitt, 1997), or incompatible personal learning styles (Bernold, Spurlin, & Anson, 2007). It is suggested that loss of interest in engineering programs may be associated with the dominance of lecture formatted classes (Blickenstaff, 2005), which account for more than 95% of engineering courses (Deshpande & Huang, 2011). Mayo (2007) describes five reasons that SGs can improve interest and retention of STEM majors: massive reach, effective learning paradigms, enhanced brain chemistry, increased time on task and better learning outcomes. Implementing games in K-12
can also expose students to STEM professions in a manner that is fun and engaging, which could increase recruitment and the retainment of college-bound students in STEM majors.

With so much interest in technology and specifically, gaming, more and more focus outside of the research world is being placed on the potential that games may have as an educational tool. The *NMC Horizon Report: 2013 Higher Education* was developed to inform education leaders, policy makers, and faculty about new and emerging technology and its potential impact on teaching, learning, and research (Johnson, et al., 2013). A key trend noted in the report is the evolution of teaching in higher education to incorporate more informal learning such as online learning, hybrid learning, and collaborative models. Taking into account daily hours spent online by both students and the public in general, there is a great potential to incorporate this style of learning to reach and connect many students. Programs such as The National STEM Video Game Challenge promoted by the US government are also on the rise. Established by President Obama in 2010, the Video Game Challenge calls for middle and high school students to design STEM related games to promote learner independence (Robertson & Howells, 2008), systems thinking, and higher-order skills that are fundamental to STEM learning (Resnick, 2012). The US Congress has also launched the E-TECH Caucus for the purpose of educating policymakers and the public about the benefits that the gaming industry can have on education and the economy (Levine M. H., 2011). Additionally, in 2012 the first national policy initiative on digital gaming's role in education, health, civic engagement, and numerous other areas was introduced (Toppo, 2012).

Although research is still ongoing as to the effectiveness of game-based learning (GBL) and the principles and mechanisms that enhance it, past research suggests that games can increase student's engagement and that there is a place for SGs at schools (Van Eck, 2006; Mayo,
GBL has been found to benefit soft skills such as critical thinking, creative problem solving and teamwork (Johnson, et al., 2013; Gee, 2004) as well as improve learning retention, cognitive development and socialization, among others (Squire, 2008; Kirriemuir & McFarlane, 2004; Levine & Vaala, 2013; Van Eck, 2006). One of the reasons for these benefits is that GBL caters to different learning styles than traditional lecture based learning. By presenting material to students using GBL as a supplement to the traditional methods, a greater proportion of students' learning styles could be accommodated. SGs can also be designed to utilize accepted learning orientations to encourage enhanced cognitive development among students. Learning orientations include behaviorism, cognitivism, humanism and constructivism and are each composed of multiple psychological theories attempting to explain the mechanisms by which learning occurs (Merriam & Caffarella, 1999; Smith, 1999). This chapter provides an overview of GBL and SGs and their potential to improve cognitive development, professional skills and the learning experience.

Environmental management is a discipline that continues to acknowledge the importance of interdisciplinary collaboration and a systems perspective (Hoekstra, 2012; Rusca, Huen, & Schwartz, 2012), which would seem to be a good fit for the development of SGs. This chapter presents a state of the art review of serious games in regard to environmental management. The purpose of the review is to determine the state of serious games in the environmental management field and insight into their variation pertaining to theme, objective, intended participants, game type and availability, among others. Environmental games include themes such as water resource management, ecology, irrigation, and conflict resolution among others and could be applied in an educational setting for courses relating to civil engineering, environmental engineering, environmental science, and urban planning.
The remainder of the chapter is organized as follows. Section 2 presents a background on GBL including associated information about learning principles, learning orientations and serious games. Section 3 reviews the literature on GBL with the objective of determining the prevailing outlook for GBL as an effective pedagogy for instruction. In section 4, the methodology is explained and identification of relevant games for environmental management are presented and discussed. Finally, the concluding remarks, potential for future work and limitations of the study are given in the last section.

2.2 Game-Based Learning (GBL)

GBL is a pedagogical method of learning that utilizes role-plays, board games, card games or VGs to promote retention of learned material and cognitive development. For traditional lecture-driven classes, learning occurs in an environment (the classroom) outside the context of the material being taught. On the other hand, the learning environment in a game is relevant to the subject and allows players to apply and practice what they have learned within an authentic context; this style of learning has been shown to be more effective than purely lecture-driven learning (Van Eck, 2006). At the foundation of GBL methods are key mechanisms (fundamental aspects) and principles (underlying concepts) that have been identified as important elements for learning (Perrotta, Featherstone, Aston, & Houghton, 2013). The most commonly supported mechanisms for a successful GBL experience include rules, goals, fictional settings, progressively difficult goals, interactivity and student control, uncertainty, immediate and constructive feedback, situated cognition, and social elements (Perrotta, Featherstone, Aston, & Houghton, 2013; Annetta, 2010; Squire, 2008). These elements are implemented differently depending on the type of media, i.e. board game versus video game, but follow similar themes nonetheless.
Based on the work of Caillois (1962), Frasca (1999) introduced a classification system in which games are categorized into two groups: paideia and ludus. Ludus games are those that result in winners and losers (e.g. chess or Pac-man) and are more complex. Paidea games, on the other hand, have no true winners or losers (e.g. merry-go-round). The distinction is important because ludus games can create an element of competition, which serves to instill a sense of motivation and drive to perform at a higher level in the game than one's opponent (player or computer). Competitive play encourages learning material more completely and utilizing critical thinking skills to apply the learned material in a more effective way than other players. Paidea games would therefore not be considered in the realm of GBL, as they often cannot create the element of competition that would motivate students as in the way of ludus games.

In addition to a paidea and ludus characterization of games as a whole, Frasca (1999) also used this system to classify game rules. Paidea rules establish how the game is played and ludus rules explain how the game is won or lost. For example, in the arcade game Pac-man, paidea rules establish that the player can move up, down, left and right; points are earned by eating Pac-dots and a life is lost if Pac-man contacts one of the enemies. The ludus rules for Pac-man determine that a player loses when he runs out of lives and wins when he eats all the Pac-dots and progresses to the next level. In addition to rules, two other elements are used to interact with the player and create the platform where learning occurs. These elements include gameplay and narratives (Ang, 2006). Learning mechanisms and learning orientations provide the theoretical foundation as to the efficacy of GBL as a pedagogical tool.
2.2.1 Learning Principles

Learning principles have been established in the field of cognitive science to explain concepts that underlie effective learning. Research regarding GBL and SGs often explore these principles, trying to identify game design elements that incorporate specific learning principles which support an intended learning outcome. In his book "What Video Games Have to Teach Us about Learning and Literacy," James Gee (2004) identifies 36 learning principles that can be used as a template for designing successful VGs. The implementation of these principles in educational games could also provide opportunities for students in the classroom setting. The following are a few of the most researched learning principles in the literature about GBL and SGs:

**Motivation:** One of the most researched learning principles connected with GBL is motivation or interest in the material being taught. Motivation plays an important role in students’ initial engagement and affects their intensity and persistence towards learning (Corti, 2006; Dorn, 1989; Annetta, 2010). Related to motivation is the notion that students interested in games will be more likely to spend more time than they would for pencil and paper homework. The result of a study by Jones (2003) which surveyed 1162 students from 27 colleges and universities revealed that 65 percent of college students play video, computer or online games regularly or occasionally. If games with worthwhile learning objectives are designed in which students enjoy participation, the time spent learning could significantly increase.

**Flow:** The *flow* concept was introduced by Csikszentmihalyi (1991) to explain the optimal experience resulting from the complete immersion of oneself in a challenging environment which produces intrinsic motivation, clear goals, a high degree of control, intent focus and lost awareness of time. In respect to video games, flow is the experience of being in "the zone" (Chen, 2007), a state of mind common for digital natives and undoubtedly observed
by their parents as characteristically involving starring at a TV or computer monitor for hours on end with little regard to their surroundings. Research has shown that the flow state in SGs improves learning (Webster, Trevino, & Ryan, 1993) and is an element that many game developers have tried to incorporate into educational games.

**Situated cognition:** As mentioned earlier, situated cognition is the ability for students to experience scenarios in a virtual world (for digital games) or role-playing games in the classroom provides an embodied experience where learning takes place in a contextualized environment. This concept can be used to prepare students for actions that would occur in real-life situations as opposed to learning accomplished in traditional classrooms. Students can learn through various modalities (words, actions, objects, artifacts, symbols, texts, etc.) in the game's environment and receive direct feedback based on the effect of their actions (Gee, 2004). Not only could students gain experience related to their field, but they could also participate as different parties involved in a project, such as citizens, scientists, politicians, environmentalists, etc. to understand the different perspectives in interdisciplinary conflicts.

**Socialization:** Many games also include opportunities for socialization (Levine & Vaala, 2013; Van Eck, 2006; Squire, 2008), normally through the use of teams or as role players addressing different issues. Students playing collaborative SGs communicate with their peers as they navigate the game, which provides the added benefit of enhancing students' social skills. Research has identified development of certain skills, such as: communication, negotiating skills, group decision making (Kirriemuir & McFarlane, 2004) in association with multi-player games.
2.2.2 Learning Orientations

The most commonly recognized learning orientation models include behaviorism, cognitivism, humanism and constructivism (Smith, 1999). Each orientation can be distinguished from the others by its own characteristic description of the mechanism or process by which learning occurs. Although each orientation can be distinguished on this basis, it is important to note that each is not completely mutually exclusive. The multiple learning theories that arise from each learning orientation are of great importance to the notion of GBL as they encompass the principles behind “how” and “why” SGs can teach what they are intended to teach. So far, only a few studies (Hense & Mandl, 2012; Wu, Hsiao, Wu, Lin, & Huang, 2012; Wu W.-H., Chiou, Kao, Hu, & Huang, 2012) have analyzed this link between the theoretical foundation of learning and digital games. Understanding which theories are the most effective for learning the intended outcome (knowledge acquisition, skill development, education or training) can help educators decide which to use with their students and also assist game developers in creating more effective games. The following is a brief description of each of the four main learning orientations.

Behaviorism: Developed by Watson (1913), Thorndike (1898) and Pavlov (1927) in the early twentieth century, behaviorism is one of the earliest of the four orientations (Merriam & Caffarella, 1999). The main principle common to behaviorist theories is that learning is produced through stimulation and reinforcement and is manifested by a change in behavior (Smith, 1999). In a gaming environment, reinforcement can be represented by positive reinforcement, such as mastering a sequence of tasks, beating a level, earning tokens or earning a high score, and by punishment, such as losing a virtual life, failing a level, losing tokens or losing rank (Hense & Mandl, 2012). It is behavior, not internal thought process that is the focus of behaviorism and
this behavior is proposed to be shaped by the learners’ environment, not by any mechanism within the learner himself (Merriam & Caffarella, 1999). As a result, behaviorism is best suited for learning skills that require little cognitive processing such as acquiring factual knowledge, memorizing processes, or developing motor skills (Hense & Mandl, 2012).

Cognitivism: In contrast to behaviorism, cognitivism focuses on an individual’s mental process, not only his environment (Smith, 1999). Instead of viewing learning as isolated events and actions that occur when our minds passively exchange stimuli with an appropriate response, the cognitive orientation dictates that it is an individual’s active mental process that puts the pieces together to gain insight into the solution of a problem (Merriam & Caffarella, 1999). Cognitivist learning de-emphasizes the focus on overt observable behavior and instead centers on the cognitive processes such as thinking, concept formation, problem-solving and information processing (Ertmer & Newby, 1993). Games that support theories of cognitivism typically involve problem-solving by way of a game's narrative (Hense & Mandl, 2012). Information embedded into the storyline, the context of the game and the players own experiences encourage critical thinking as a means of solving complex problems. Adventure and digital role-playing games are examples of the type of games that feature narrative and problem-solving. Games within the cognitive-oriented learning perspective work well for acquiring knowledge and comprehending complex problems (Hense & Mandl, 2012).

Humanism: As opposed to behaviorism and cognitivism, which break down learning into a rational and scientific model predicated on outcomes, humanism is focused on the human potential for growth (Smith, 1999). Major contributions in the area of humanist theories of learning come from Abraham Maslow (Maslow, Frager, & Fadiman, 1970) and Carl Rogers (Rogers & Allender, 1983). A main principle of humanistic learning is a strong focus on the
individual and personal development toward the goal of achieving the best that one may achieve, a state deemed self-actualization by Maslow (Merriam & Caffarella, 1999). For Maslow, self-actualization is the pinnacle of a hierarchy of needs that one strives to achieve, with more basic needs that must be met first, such as food, security and friendship (Maslow, Frager, & Fadiman, 1970). Rogers insights into education and learning concentrated on the connection of a person and their own experiences that result in personal growth and development (Merriam & Caffarella, 1999). Characteristics of learning according to Rogers include: (1) personal involvement; (2) self-initiated; (3) pervasive; (4) evaluated by the learner; and (5) essence is meaning (Merriam & Caffarella, 1999).

Constructivism: Constructivism is the most recently developed learning orientation and incorporates some of the same ideas as its predecessors. Constructivism describes learning as a way to construct meaning from experience (Merriam & Caffarella, 1999) and is focused on a holistic perspective of learning which incorporates experience, perception, cognition and behavior (Kolb, 1984). There are two perspectives in constructivism; individual and social (Merriam & Caffarella, 1999). The individual-constructivist perspective describes learning as “meaning-making” of an individual and is dependent on the individual’s previous and current knowledge base (Merriam & Caffarella, 1999). Games that follow individual-constructivism need to contain challenging problems that build upon previously known and newly learned knowledge which require the player to analyze the situation, test solutions and reflect on the outcomes. Strategy and design games work particularly well for this orientation of learning as do games that use simulations to represent reality (Hense & Mandl, 2012). Social-constructivism on the other hand, defines learning as occurring when individuals interact socially, participating in conversation and activities concerning a shared problem or task (Merriam & Caffarella, 1999). In
a game setting, this form of learning occurs when players communicate and cooperate face-to-face or through online media such as forums, chats, virtual worlds or video/digital messaging (Hense & Mandl, 2012). The main principles derived from the constructivist orientation of learning that can be applied in regard to games are best described by an experiential learning theory (Smith, 1999). The experiential learning model contains four stages beginning with a concrete experience (Kolb, 1984). From this first experience, the learner progresses to an observation and reflection period followed by the formation of abstract conceptualization and finally to the testing of the learned concepts in new situations (Kolb, 1984). Experiential learning is well-suited to games due to the fact that many games, such as adventure and role-playing games allow the player to learn by direct participation.

A meta-analysis by Wu et al. (2012) investigated the prevalence of learning theories in game-assisted learning and found that the majority of gaming-related published studies did not address learning theories. Out of 669 studies, only 89 contained learning orientations as foundation of the game. Wu et al. (2012) also categorized the studies that did incorporate learning theory foundations in their discussion of gaming based upon the established learning orientations: behaviorism, cognitivism, humanism and constructivism. Some learning orientations were more frequently noted than others: constructivism (51%) and humanism (22%), followed by cognitivism (14%) and behaviorism (13%). However, the only learning theory associated with the humanist orientation of learning in this study was experiential learning, which is more commonly associated with constructivism. In this case, constructivism would account for 73% of games utilizing learning theory as a foundation of the game. Of the studies that cited learning orientations as a foundation for the game, 92% were classified by positive outcomes (simulate "real world" experience and promote questioning and active experimentation
by learners), 2% by negative outcomes and 6% by neutral outcomes (Wu W.-H., Chiou, Kao, Hu, & Huang, 2012).

2.2.3 Serious Games

There is a variety of nomenclature utilized for referring to technology or games that are intended for educational or instructional purposes such as E-learning, authentic instruction, alternative purpose games, synthetic learning environments and edutainment among others. The focus of this paper is on the genre of “serious games (SGs).” There are numerous definitions for serious SGs, often varying depending on the different perspectives and purposes that they were developed to explain (Susi, Johannesson, & Backlund, 2007). A common theme in most definitions, however, is that SGs are not designed solely for entertainment purposes, but as a tool to educate, train and inform users (Abt, 1987; Michael & Chen, 2005; Susi, Johannesson, & Backlund, 2007). That is not to say, however, that SGs are not entertaining or fun for players, only that entertainment is not the primary focus of such games (Michael & Chen, 2005). Some also argue that any entertainment game could be converted to a serious game if an educational or training purpose could be developed for the game (Susi, Johannesson, & Backlund, 2007), while others believe that the utility of purpose must be present during the development of a game if it is to be considered a SG (Girard, Ecalle, & Magnan, 2013).

Many researchers believe that serious games incorporating digital GBL create the greatest potential for student learning over other media (Prensky, 2001; Gee, 2004; Squire, 2008). The creation of immersive and engaging environments in which players can explore and learn is more feasible than ever with today's technology. By utilizing available technologies in the development of SGs, students will be given the opportunity like never before, to experiment
with realistic simulations using animations, graphics and interactive environments that effectively explain and illustrate course content and develop students’ skills (Deshpande & Huang, 2011).

Digital SGs have been developed for subjects including health care, military training, business management, engineering, physics, and medicine for the positive impacts that they have been found to support, including analytical and spatial skills, strategic skills and insight, learning and recollection capabilities, psychomotor skills, visual selective attention improved self-monitoring, problem recognition, problem-solving, decision making, better short-term and long-term memory and increased social skills (Susi, Johannesson, & Backlund, 2007).

Of course, there are some drawbacks to digital SGs. Many educators do not have the time or skill to develop games on their own and having them designed by professionals is costly and impractical (Whitton, 2012). To compound this issue, educators would be required to spend additional time learning the game, developing methods to implement it in the classroom and convincing school stakeholders of its educational benefits, a time-consuming venture some educators might rather forgo (Kirriemuir & McFarlane, 2004). Additionally, not all games are designed with well-established learning theories in place, leading to players failing to acquire the intended results. Therefore, research into the most effective design models is ongoing (Annetta, 2010; Gunter, Kenny, & Vick, 2006; Kiili, 2005; Sweester & Wyeth, 2005; Wilson, et al., 2009; Garris, Ahlers, & Driskell, 2002) for producing successful learning through SGs.

2.3 Review of the GBL Literature

One of the first reviews related to GBL was that of Randel et al. (1992) who investigated the effectiveness of games and simulations for educational purposes. The review covered 68
studies published between 1963 and 1991 and was the first review to separate the games and simulations into categories related to a field of interest: social sciences, math, language, arts, physics, biology and logic. The results of this study, determined by using posttests of games/simulations compared to those of the posttests of traditional teaching techniques, suggested that 56% of the studies showed no difference in students’ performance when either teaching method was utilized, 32% favored games/simulations, 7% favored games/simulations but had questionable controls, and 5% favored traditional teaching techniques. In addition to efficacy of learning, Randel et al. (1992) also reported on the students’ interest in and retention of the learned material over time when the material was taught via games/simulations versus traditional teaching techniques. Of the 14 studies that reported these data, 71% significantly favored games/simulations to increase retention of material over time, while 29% found no variability in retention rates between games/simulations and traditional teaching techniques. In 86% of these studies, students were also found to be more interested in learning from games/simulations than from traditional teaching methods. Another observation revealed that games/simulations with a clearly stated goal (such as math, physics and language arts) were more effective than those that were more general (such as social sciences). Randel et al. (1992) concludes that the effectiveness of using games/simulations for teaching is dependent on subject matter, but that even for subjects that do not or only minimally increase the percentage of students posttest performance should be considered for other game/simulation benefits such as learning retention and interest. Lastly, the methods used to determine the effectiveness of games/simulations and the features responsible for such educational effectiveness in studies must be reported so that analyses can be performed and effects measured (Randel, Morris, Wetzel, & Whitehill, 1992).
Wolfe (1997) reviewed business games studies from 1986-1997 related to strategic management. This study encompassed games that featured three criteria: predefined, objectively measured learning objectives; controlled or equivalent group research designs; and objectively assessed learning outcomes. GBL was compared to learning via case studies, the preferred method for teaching strategic management, focusing on the difference between the substantive and procedural outcomes of the two methods. Wolfe (1997) summarizes a number of the studies that met the above requirements and concluded that knowledge-level gains of students increased in all studies except for those that used case method protocols to determine knowledge scores. In that instance knowledge-gain was equal for GBL and case-based curriculum. Procedural outcomes of the studies, relating components of the games, such as complexity, group size and role of the instructor, to learning effectiveness were less fruitful because many of the reviewed studies did not record this information (Wolfe, 1997).

In an effort to connect previous literature on the effectiveness of games, Hays (2005) conducted an extensive literature review of instructional games with an emphasis on empirical research. Out of 274 studies considered, 62% could not be used because they contained or were based on: (1) the authors’ opinions of the potential of the game, (2) game design and analysis, (3) simulation or computer-based instruction studies (not considered games), (4) major methodological problems or (5) proposals for future research. Based on the 38% of studies that were considered, Hays (2005) observed that empirical research on the effectiveness of games is “fragmented” with literature often focused on different tasks, age groups, and types of games. He affirms that some research reveals games can be effective tools for learning, but asserts that there is no evidence that games are the preferred method of instruction for all situations. Additionally, students’ comprehension of intended learning outcomes was found to increase with instructional
support for gameplay and the inclusion of feedback mechanisms and a debriefing session upon completion of a game (Hays, 2005).

A meta-analysis by Vogel et al. (2006) investigated studies concerning games and interactive simulations that included cognitive gains or attitudinal changes as one of the main hypothesis of the paper. If a study was to be utilized, it was also required to have reported statistics evaluating gaming and interactive simulations against traditional classroom teaching. The meta-analysis considered 248 studies of which 13% met inclusion requirements and were used in the analysis. Studies that were not used contained numerous problems including methodological and reporting flaws, no control group, and no statistical data, making the studies unusable for research purposes. The authors concluded that application of games or simulations resulted in significantly higher cognitive gains and improved attitudes towards learning than with the use of traditional teaching techniques. The study analyzed variables including gender, learner control, type of activity, age, realism and user; and determined that despite all variables, higher cognitive gains and attitudes were maintained consistently compared to traditional methods.

Another meta-analysis by Ke (2009) looked at both qualitative and quantitative evidence for computer games being used for learning and the factors, if any, that promote the effectiveness of instructional games. In total, 256 studies published between 1985 and 2007 were investigated, out of which 89 were used in the meta-analysis. The studies were classified among five categories based on the purpose of the research and each was analyzed. The largest category was concerned with the effects of instructional gaming on learning (65 out of 89). Out of the 65 studies, the author found that 52% reported significant positive effects for the use of computer-based games, 26% reported mixed-results (positively affecting certain learning outcomes, but not others), 18% reported no difference and only one (2%) study reported that conventional
instruction was more effective than the corresponding instructional game. From the second category, exploring effective instructional game design (17 out of 89), Ke (2009) determined that instructional support features are a necessary component of effective games. Without instructional support, the player will learn how to play the game, instead of learning the intended outcome that the game was designed to teach. Upon analysis of the third category, exploring GBL activity or pedagogy (9 out of 89), the author suggested that studies investigating computer games for learning should focus on how games can be aligned with accepted learning pedagogies, finding this approach to be beneficial. Analysis of the fourth category, evaluating the influence of learner characteristics on the GBL process (10 out of 89), indicated three notable characteristics reviewed in the studies: gender, cognitive style and socio-economic status. The effect of gender on the GBL process was mixed, but the author offered a potential explanation; that gender influences gameplay and learning process more than learning outcomes. In terms of an individual's cognitive style, studies suggest different styles influence performance in team settings, but do not specify the effect on individual learning. It was also recognized that individuals characterized by low socio-economic status and ability enjoy games the most, but have more difficulty learning target knowledge from games. The final category, investigating cognitive or motivational processes during game play (4 out of 89), contained descriptive and anecdotal studies, but addressed the potential of games to be an anchor to activate learner's cognitive, metacognitive and motivational processes. Ke (2009) concluded that the best practices for designing and applying instructional games is to align and integrate three clusters of key variables: learning, learner and instructional design.

Perrotta et al. (2013) reviewed studies published from 2006-2012 for the purpose of understanding the impact that GBL could have on students and schools. Of the initial group of
485 studies, 31 studies were selected for further review. The focus of the studies were far-reaching and tested a variety of hypotheses including the impact of VGs on learning outcomes, cognitive performance and knowledge, skills, and performance gains, among others. The authors found that the literature was divided as to the effect that games can have on overall academic achievement, but the studies predominantly indicated improved problem-solving skills and knowledge acquisition associated with gaming. Studies focusing on the impact of games on student motivation and engagement indicated positive results. Although only one meta-analysis of the reviewed studies evaluated whether games can affect students' attitudes towards learning, it did illustrate a positive relationship. Concerning the impact that GBL might have on schools, Perrotta et al. (2013) recognized that overall, the results "appear to demonstrate a positive relationship between gaming in the classroom, learning outcomes and motivation and engagement." It was determined that, in general, educators view educational games favorably, but profess it would require very strong evidence to consider replacement of traditional learning styles with a game-based approach. For now, application of games as a supplement to current practices is more feasible until more conclusive research investigating the relationship between VGs and academic achievement is available and incompatibilities between GBL and formal practices is overcome.

Most recently, a meta-analysis by Girard et al. (2013) examined the effectiveness of VGs and SGs on learning and engagement. Among the reviewed were studies encompassing VGs and SGs from 2007-2011 which adhered to the following criteria: classifiable as a VG or SG, containing empirical data from game evaluations, utilizing “pre-test – game – post-test” design and contained a control group. There were 9 studies containing 11 games in total that were deemed suitable based upon application of the above criteria in evaluation of the games.
Information regarding population characteristics, experimental methodology and procedure, and measures of learning effect and engagement were reported. The effectiveness of learning was evaluated based on a comparison of the pre-tests and post-tests of gamers versus control groups. Out of the 11 games: 27% had a positive effect on learning, 64% had no beneficial effect, and one game (9%) had mixed results. The magnitude of the learning effect was not discernible because of a lack of precise quantitative data. The authors were neither able to prove that SGs nor VGs based teaching elicited higher learning gains for those students in the control groups. It was also indeterminate as to whether engagement and motivation were significantly increased among the SG/VG students. This lack in conclusiveness was due to having only examined 9 studies. However, it was concluded that the combination of results achieved, in conjunction with prior literature regarding the effect of engagement, lead them “to think that SGs might be powerful tools for learning.” One reason the authors cited as responsible for the inability to draw reliable conclusions from analysis of the studies was on behalf of inconsistency among control groups; some of which contained students exposed to traditional teaching techniques, while others either played a different game or received no additional training at all. The variability of SGs and VGs, in addition to other forms of game-based learning (simulations, role-playing games, etc.), proved to be another obstacle in comparing studies. In addition, Girard et al. (2013) concluded that elements of each game such as quality of design, game mechanics, devices used for play, game scenario, integration of additional elements, context of use, etc. will affect the efficacy of a game and should therefore be considered specifically and at an individual level.

Overall, there are a few unifying conclusions to be derived from the described reviews of the GBL literature: (1) the effectiveness of games is not universal for educational purposes, it depends on the design and components of each game; (2) many studies of educational games
contain methodological problems and lack quantitative results, making it difficult to assess the accuracy of the findings; (3) there is a need to investigate longitudinal studies to determine the influence, if any, on the effectiveness of games; (4) debriefing is an important element of GBL, allowing participants time to reflect over their experiences and understand the connections between gameplay and instructional objectives; and (5) GBL can increase motivation and engagement, which has beneficial effects on learning outcomes.

2.4 Environmental Management Games

Environmental systems involve complex and interdisciplinary characteristics that not only contribute to the difficulty of their management, but also in the challenge to educate students and stakeholders on such matters. This review provides a compilation of environmental management games that can assist educators and researchers locate a tool appropriate for their objective, whether it be education, negotiation, etc. Research into the potential effects and uses of GBL, especially those that feature learning orientations as their framework has revealed many positive benefits that could undoubtedly help the teaching and understanding of environmental management. There are a few reviews of games for engineering in other areas (e.g. Katsaliaki and Mustafee (2012) surveyed sustainable development games and Deshpande and Huang (2011) reviewed simulation games for various areas of engineering), but none for environmental management for higher education students, professionals or stakeholders. The review also details what topics or subject areas have received the most interest and which need further development. The timetable for implementation could be fast approaching, as SGs continue to gain momentum and see improvements in pedagogical and usability design. The NMC Horizon Report (2013) expects to see widespread adoption of games and gamification in higher education by 2015-2016.
2.4.1. Dataset

Games were identified by searching the OneSearch databases for keywords including: games, player, education or teaching, in combination with other keywords such as environmental, natural resources, water, water resources, etc. The same process was also repeated on Google and Google Scholar search engines, for which the first 50 results were checked. Information regarding the remaining games was obtained from additional literature search. Games were excluded if they did not meet the following criteria: (1) intended for use by stakeholders, professionals and/or in higher education; (2) met the definition of SG; and (3) intended for educational or instructional use.

Examples of games that were not considered suitable for inclusion were the well-known simulations SimEarth (Wright & Haslam, 1990), which teaches global ecology and earth science and SimCity 4 (D'Artista & Hellweger, 2007), which can be used for teaching urban hydrology and water management. These games were not included in the survey because they do not establish hard ludus rules and their development was not for educational or instructional use. Similarly, face-to-face role-plays such as The Externalities Game, The Environmental Management Game, The Location Game and The Agricultural Policy Game (Bazan, 1976) were not discussed in conjunction with this paper as they fail to provide hard ludus rules and are more similar in design to that of a simulation game. As previously stated, addition of ludus rules to a game can effectively transform any paidea game into a ludus game, but for the purposes of this paper, only games containing predefined, hard ludus rules are considered.

Twenty-five serious games were found that met the inclusion criteria necessary to be considered a serious game related to environmental management. Table 1 lists these games chronologically by name and includes a source where information pertaining to each game can
be found. The games included in Table 1, range from the Irrigation Management Game, developed in 1994 to the Climate Change Survivor game, created in 2013. Figure 1 shows the number of games that have been developed over this time frame. This figure shows a positive trend in development of environmental management SGs, consistent with the reported expansion of the development of educational games recent history (Prensky, 2001; Susi, Johannesson, & Backlund, 2007).

2.4.2 Variables for Analysis

In order to analyze the 25 environmental management games listed in Table 1, specific information about each game was recorded. Pertinent information was extracted from academic papers, the game’s website or by playing the games. The following variables were determined to be of interest:

1. **Theme**: the main focus of the game, examples include climate change, water management, ecosystem ecology, etc.

2. **Player’s role**: the identity of the character that a player assumes in the game, for example, in the Irrigania game (Seibert & Vis, 2012; Pierce & Madani, 2013) each player acts as a farmer in charge of irrigating crops.

3. **Game objective**: the specific result that a player aims to achieve by the end of the game.

4. **Number of players**: identifies the number of players that can participate in the game.

5. **Participants**: establishes the group of players the game was developed for: students, professionals or stakeholders.

6. **Type of game**: the classification of each game, whether the game is a board game, card game, digital game (electronic game with a user interface and visual feedback), online
digital game (digital game that is played online), and hybrid simulation game (role-play, board game or card game that utilizes a computer simulation to produce results that progress the game).

7. **Graphics**: the dimensions of the game’s visual display, either 2D or 3D.

8. **Availability**: identifies how the game can be obtained.
<table>
<thead>
<tr>
<th>Year</th>
<th>Game Name</th>
<th>Source</th>
<th>Theme</th>
<th>Player's Role</th>
<th>Game Objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>1994</td>
<td>Irrigation Management Game</td>
<td>Burton (1994)</td>
<td>Irrigation, water management, conflict resolution</td>
<td>Irrigation agency staff, farmer</td>
<td>Develop understanding of issues involved in managing an irrigation system and the importance of communication to the system performance.</td>
</tr>
<tr>
<td>1998</td>
<td>Geology Explorer</td>
<td>oit.cs.ndsu.nodak.edu/menu/Saini-Eidukat et al. (2002)</td>
<td>Geology</td>
<td>Geologist</td>
<td>Travel to a newly discovered Earth-like planet on an expedition to locate a particular mineral and map a metamorphic terrain.</td>
</tr>
<tr>
<td>1999</td>
<td>Build a Prairie</td>
<td>bellmuseum.umn.edu/games/prairie/build/tb1.html</td>
<td>Environmental management, ecology</td>
<td>Ecosystem restorer</td>
<td>Restore a threatened prairie to its natural state by selecting the appropriate plants and animals to be returned to the land.</td>
</tr>
<tr>
<td></td>
<td>Samba Role Play</td>
<td>Boissau et al. (2004)</td>
<td>Environmental management</td>
<td>Farmer</td>
<td>To allocate land, labor and capital in order to grow rice, clear forests, plant cash crops, purchase animals, etc. to be able to provide for your family and pay workforce.</td>
</tr>
<tr>
<td></td>
<td>The Great Green Web Game</td>
<td>web.cs.wpi.edu/~claypool/qsp/green/</td>
<td>Environmental education, energy use</td>
<td>Yourself</td>
<td>To test your knowledge on how consumer choices affect the environment.</td>
</tr>
<tr>
<td>2003</td>
<td>Industrial Chlorine Transport Metagame</td>
<td>Bots and Hermans (2003)</td>
<td>Risk analysis, environmental impact analysis</td>
<td>Polymer company, chlorine gas company, railroad company, government, citizens</td>
<td>Role players must negotiate and make decisions based on their interests in regards to an industrial chlorine transportation company that wishes to increase its production.</td>
</tr>
<tr>
<td></td>
<td>Slyvopast</td>
<td>Etienne (2003)</td>
<td>Silvopasture management, conflict resolution</td>
<td>Shepherd, forester</td>
<td>Promote awareness of the difficulties in silvopasture management plan negotiations between forestry practitioners and herdsmen.</td>
</tr>
<tr>
<td>2004</td>
<td>River Basin Game</td>
<td>Lankford et al. (2004)</td>
<td>Irrigation, water management, common pool resources, conflict resolution</td>
<td>Farmer</td>
<td>Players controlling different sections of a river basin and try to manage water use for farming under different scenarios. Promotes understanding of a catchment, factors controlling access to water, conflict dynamics and allows participants to react to different scenarios.</td>
</tr>
<tr>
<td></td>
<td>Industrial Waste Game</td>
<td>Hirose et al. (2004)</td>
<td>Environmental education</td>
<td>Industrial plant manager</td>
<td>Develop an understanding of and solutions for the social dilemma between individual interest of hazardous dumping and the social cost it creates.</td>
</tr>
<tr>
<td>2006</td>
<td>Shrub Battle</td>
<td>Depigny and Michelin (2007)</td>
<td>Agricultural management, farming systems, conflict resolution</td>
<td>Farmer, plants</td>
<td>To help make future rural planners aware of the complex relationships between landscape dynamics and agricultural practices in farming systems.</td>
</tr>
<tr>
<td></td>
<td>Climate Challenge</td>
<td>bbc.co.uk/sn/hottopics/climatechange/climate_challenge</td>
<td>Climate change</td>
<td>President of the European Nations</td>
<td>Make decisions to confront global climate change at home and abroad while maintaining political support, protecting the environmental and improving the economy.</td>
</tr>
<tr>
<td>2007</td>
<td>Butorstar</td>
<td>Mathevet et al. (2007)</td>
<td>Environmental management, water management, ecology, conflict resolution</td>
<td>Reed harvester, stockbreeder, naturalist, hunter</td>
<td>Promote awareness of (1) biological and hydrological interdependencies and their dynamics on different spatial and temporal scales; (b) the technical and socioeconomic factors involved in different types of reedbed use; (c) the usefulness of negotiation for establishing collective management rules.</td>
</tr>
<tr>
<td>Year</td>
<td>Game Name</td>
<td>Source</td>
<td>Theme</td>
<td>Player’s Role</td>
<td>Game Objective</td>
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<tr>
<td>2007</td>
<td>Atoll Game</td>
<td>Dray et al. (2006)</td>
<td>Water management, conflict resolution</td>
<td>Landowner</td>
<td>Promote sustainable water management and discussions through gameplay for which each player is responsible for providing enough clean water to his family.</td>
</tr>
<tr>
<td>2008</td>
<td>Catchment Detox</td>
<td>hcatchmentdetox.net.au/home/</td>
<td>Ecosystem ecology, watershed management, planning</td>
<td>Planner</td>
<td>To create a thriving and environmentally healthy catchment by managing agriculture, forestry, industry, tourism and ecosystem activities.</td>
</tr>
<tr>
<td>2009</td>
<td>Globalization of Water Role-Play</td>
<td>utwente.nl/water/research/games Hoekstra (2012)</td>
<td>Globalization, water management</td>
<td>Head of State, Minister of Environment and Agriculture, Minister of Trade and Foreign Affairs</td>
<td>To convey the message that wise water resources management is not simply a national matter, but to be understood in a global context.</td>
</tr>
<tr>
<td>2011</td>
<td>River Basin Game</td>
<td>utwente.nl/water/research/games Hoekstra (2012)</td>
<td>Irrigation, water management, common-pool resources, conflict resolution</td>
<td>Farmer</td>
<td>Players controlling different sections of a river basin and try to maximize benefits of farming. Promotes understanding of a catchment, factors controlling access to water and conflict dynamics.</td>
</tr>
<tr>
<td>2011</td>
<td>LIBRA River Basin Simulation Game</td>
<td>Rusc et al. (2012)</td>
<td>River basin planning</td>
<td>River basin authority, city water supply utility, irrigation district</td>
<td>To give participants insight into the multi-disciplinary character of integrated water resources management, with a strong focus on water demand management.</td>
</tr>
<tr>
<td>2011</td>
<td>Fate of the World</td>
<td>fateoftheworld.net</td>
<td>Climate change</td>
<td>International policy maker</td>
<td>Play through different missions involving sociopolitical events, energy consumption, population growth, natural disasters, etc. and make decisions with the goal of improving global climate change patterns.</td>
</tr>
<tr>
<td>2012</td>
<td>Irrigania</td>
<td>irrigania.ch/ (Seibert &amp; Vis, 2012)</td>
<td>Irrigation, water management, common-pool resources, conflict resolution</td>
<td>Farmer</td>
<td>Utilize shared surface and ground water resources within a village of other farmers to irrigate crops and become the most profitable farmer.</td>
</tr>
<tr>
<td>2012</td>
<td>Aqua Republica</td>
<td>aquarepublica.com/</td>
<td>Integrated water resource management, conflict resolution</td>
<td>City planner</td>
<td>To promote sustainable water resource management through experience gained by making decisions to manage a catchment in real life scenarios.</td>
</tr>
<tr>
<td>2012</td>
<td>Citizen Science</td>
<td>filamentgames.com/projects/citizen-science Gaydos and Squire (2012)</td>
<td>Lake ecology</td>
<td>Citizen scientist</td>
<td>To encourage players’ active participation in society by providing the perspective that they are capable sources of legitimate science-driven community activism through the narrative of a citizen concerned about the health of a local lake.</td>
</tr>
<tr>
<td>2013</td>
<td>Climate Change Survivor</td>
<td>pacinst.org/reports/climate_change_survivor_game/</td>
<td>Climate Change</td>
<td>Yourself</td>
<td>To promote awareness of the actions that can be taken to prepare and protect ourselves from the impacts of climate change and discuss factors that make us more or less safe in regard to climate change.</td>
</tr>
</tbody>
</table>
Table 1 provides an overview of each game including its theme (column 4), player’s role (column 5) and game objective (column 6). The number of subjects for the game’s theme was kept as small as possible to emphasize the main topic of the game. For example, the chief themes present in the game Citizen Science include lake ecology and conflict resolution, however, other topics are, to a lesser degree, encountered within the game such as wetlands, flooding, and water quality. These secondary subjects are left out of thematic descriptions to provide clarity in the attempt to demonstrate each game’s individual niche in environmental management. Table 2 presents additional game information including: number of players, participants, type of game, computer graphics (2D or 3D), and availability of the game.

2.4.3 Findings

The most ubiquitous themes of the 25 games comprised conflict resolution (25%), water management (23%), irrigation (9%), ecosystem ecology (8%) and environmental education (8%). Figure 2 displays these results, where the category “other” encompasses themes with only one count (e.g., agricultural and farming management, energy, geology, globalization, risk analysis and silvopasture management). In the majority of games, player’s assumed a role of power position or decision maker such as a farmer, manager, community leader, or landowner. In these games the player usually has complete authority to make decisions that affect a larger group of individuals. In multi-role games (indicative of a multi-player game) the role of the individual players is less powerful and often in conflict with those opposing players. For example, in the Butorstar game (2007) players represent reed harvesters, stockbreeders, naturalists or hunters and each must make choices based on their role, which in turn affects the virtual wetland in the game. Each player can only control specific dynamics related to his role; a
reed harvester’s job is to maintain or increase the areas of reed harvested and the naturalist is trying to maintain and develop the reedbed as a wildlife refuge, opposing goals resulting in a conflict of interest.

![Figure 1. Environmental management games over time](image)

The five styles of game design among the 25 games analyzed included hybrid simulation game (8), online digital game (8), board game (5), card game (3) and digital game (1). Figure 3 displays the types of environmental management games developed in the field. Of the games evaluated, 7 were single player, 6 were multiple-player games with no specific number of players required, and the remaining 11 games varied between 2 and 26 players. It is important to note that many of these games, even the single player games could be modified for use by teams of players instead of by individuals. For example, although Aqua Republica is a single player game in which the player’s role is that of a city planner, a team of 3-4 students or even an entire class could work together while playing the game. The majority of the games (21 of 25) were intended for a combination of student, professional and stakeholder use, and four were created for the
general public. The majority of games accessed were 2D; only the Sustainable Delta game (Haasnoot, Offermans, van Lieshout, & Valkeringen, 2010), Fate of the World, and Aqua Republica were 3D. The games labeled “N/A” in the Computer Graphics column in Table 2 consist of those without computer graphics. One of these games is not a traditional board game however; the River Basin Game (Lankford, Sokile, Yawson, & Levite, 2004) is a 3D representation of a watershed constructed of wood. In the game, marbles are used to represent water, which flows down the game board and is captured by offshoots into a farmer’s crops. Geology Explorer (Saini-Eidukat, Schwert, & Slator, 2002) classifies itself as a 2.5-dimensional game, but is technically a 2D game with techniques that make some aspects appear 3D. Other games like Citizen Science (Gaydos & Squire, 2012) and Catchment Detox fall within this intermediate classification as well. Concerning availability, nine games are available for free online, one for purchase online, four provide directions describing play/design of the game, one supplies contact information and nine do not offer information as to the games availability.

Figure 2. Environmental management game topics
Figure 3. Type of serious environmental management games over time
Table 2. Additional information on the reviewed environmental management games

<table>
<thead>
<tr>
<th>Game</th>
<th>Number of Players</th>
<th>Participants</th>
<th>Type</th>
<th>Computer Graphics</th>
<th>Availability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Irrigation Management Game</td>
<td>10-26</td>
<td>Students, professionals</td>
<td>Hybrid simulation game</td>
<td>2D</td>
<td>Directions given</td>
</tr>
<tr>
<td>Geology Explorer</td>
<td>Multiple</td>
<td>Students</td>
<td>Online digital game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Build a Prairie</td>
<td>1</td>
<td>Students</td>
<td>Online digital game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Learning Sustainable Development Game</td>
<td>4-6</td>
<td>Students</td>
<td>Card game</td>
<td>N/A</td>
<td>Not explained</td>
</tr>
<tr>
<td>Samba Role Play</td>
<td>Multiple</td>
<td>Stakeholders</td>
<td>Board game</td>
<td>N/A</td>
<td>Not explained</td>
</tr>
<tr>
<td>The Great Green Web Game</td>
<td>1</td>
<td>Students, stakeholders</td>
<td>Online digital game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Industrial Chlorine Transport Game</td>
<td>Multiple</td>
<td>Students, professionals</td>
<td>Card game</td>
<td>N/A</td>
<td>Not explained</td>
</tr>
<tr>
<td>River Basin Game</td>
<td>Multiple</td>
<td>Students, professionals, stakeholders</td>
<td>Board game</td>
<td>N/A</td>
<td>Directions given</td>
</tr>
<tr>
<td>Industrial Waste Game</td>
<td>5-6</td>
<td>Students</td>
<td>Card game</td>
<td>N/A</td>
<td>Directions given</td>
</tr>
<tr>
<td>Shrub Battle</td>
<td>4</td>
<td>Students</td>
<td>Board game</td>
<td>N/A</td>
<td>Not explained</td>
</tr>
<tr>
<td>Climate Challenge</td>
<td>1</td>
<td>General public</td>
<td>Hybrid simulation game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Butorstar</td>
<td>8-10</td>
<td>Students</td>
<td>Hybrid simulation game</td>
<td>2D</td>
<td>Not explained</td>
</tr>
<tr>
<td>Catchment Detox</td>
<td>1</td>
<td>General public</td>
<td>Online digital game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Globalization of Water Role Play Game</td>
<td>12</td>
<td>Students</td>
<td>Computer assisted board game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Sustainable Delta Game</td>
<td>Multiple</td>
<td>Students, professionals, stakeholders</td>
<td>Hybrid simulation game (online digital game in development)</td>
<td>3D</td>
<td>Contact given</td>
</tr>
<tr>
<td>River Basin Game</td>
<td>9-15</td>
<td>Students</td>
<td>Computer assisted board game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>LIBRA river basin simulation game</td>
<td>Multiple</td>
<td>Professionals</td>
<td>Hybrid simulation game</td>
<td>2D</td>
<td>Not explained</td>
</tr>
<tr>
<td>Fate of the World</td>
<td>1</td>
<td>General public</td>
<td>Digital Game</td>
<td>3D</td>
<td>Purchase online</td>
</tr>
<tr>
<td>Irrigation Game</td>
<td>3-6</td>
<td>Students</td>
<td>Online digital game</td>
<td>2D</td>
<td>Free online</td>
</tr>
<tr>
<td>Aqua Republica</td>
<td>Multiple</td>
<td>Students</td>
<td>Online digital game</td>
<td>3D</td>
<td>Free online</td>
</tr>
<tr>
<td>Citizen Science</td>
<td>1</td>
<td>Students</td>
<td>Online digital game</td>
<td>2D</td>
<td>Not explained</td>
</tr>
<tr>
<td>Hydromonopoly</td>
<td>5</td>
<td>Students, stakeholders</td>
<td>Board game</td>
<td>N/A</td>
<td>Contact given</td>
</tr>
<tr>
<td>Climate Change Survivor</td>
<td>3-6</td>
<td>General public</td>
<td>Board game</td>
<td>N/A</td>
<td>Directions given</td>
</tr>
</tbody>
</table>
2.5 Conclusions

The purpose of the review was to determine the state of SGs for environmental management, provide insight into their potential as educational tools in higher education and identify areas of improvement. The progression of digital technology and its influence on today's youth were examined and the potential impact SGs could have in STEM education were introduced. Important topics associated to GBL were then examined including learning principles, learning orientations and SGs. Next, a review of the findings of reports and meta-analyses related to game-based learning were discussed. Finally, the methods and findings for the review of environmental management SGs were explained. The following addresses the objectives of this paper. SGs have been shown to possess the capability to manifest numerous qualities that have been connected with improved learning experiences and cognitive development, but research must continue to study the elements that have been linked to increasing the efficacy of SGs. By improving these elements, future SGs can implement new findings and expand their capacity to improve areas such as cognitive development, acquisition of factual knowledge, teamwork skills, critical thinking skills, and creative problem solving, among others. As technology, computing power and computer graphics continue to advance and become more and more a part of everyday life, particularly in the STEM disciplines, educators should embrace the tools that accompany this technological advance.

One of the current obstacles for SGs in higher education is associated with difficulties in seeking out available games. Often proving more of a challenge, it must then be ascertained whether the game is appropriate for one’s intended use. The intended learning outcomes or skill development are not always explained thoroughly and many games are not well suited for
classroom use. A centralized source for locating and obtaining information pertaining to the available educational games and their most appropriate applications, effectively an online database for SGs, would undoubtedly prove helpful for interested educators and students. Such a database could provide links to online games, directions to create a game (card game, board game, or role-play) and methods for implementation. In addition, features allowing users to provide feedback on games, collaboration between SG developers and dissemination of new information in regard to SGs. Furthermore, because methods employed in determining the effectiveness of SGs vary greatly among studies, prevention of disparities in testing procedures, such as among the control groups, necessitates development of a standardized methodology for evaluating the effectiveness of SGs.

Another impediment to the implementation of GBL is cost. Purchasing commercial games and the necessary hardware required to run them, in addition to the time spent by educators needing to learn the skills essential for game development and application all create added cost burdens to an educational system. There are suggestions to overcome this issue though; some authors suggest alternative methods, such as teachers creating low-cost games, teaching from games as opposed to with games (using off-the-shelf games) and empowering students to learn through creating games (Whitton, 2012; Van Eck, 2006).

This review of environmental management games documented 25 SGs that have been developed between 1994 and 2013. During this time the number of games has continued to increase and although no major trend in the type of game (hybrid simulation, online digital game, digital game, card game or board game) is discernible, hybrid simulations and online digital games appear to be developing with more frequency than the other groups. The games vary
considerably encompassing topics from climate change and water management to globalization, risk analysis and conflict resolution. The complexity of the games and the time required for play was also quite disparate. A problem facing the inventory of natural resource games is that a majority are not available for free online, making it more burdensome for educators to implement these games in their classrooms and even more unlikely that students would play on their own. One of the main shortcomings of the reviewed environmental management games was the omission of: (1) evaluations for assessing a game’s effectiveness; and (2) pedagogical foundations for which the game was based upon. Future research should focus on improving these areas. Frameworks have been suggested for serious game design, but few methods for evaluating a game’s effectiveness exist.
CHAPTER 3: GAMING FOR SUSTAINABLE NATURAL RESOURCE MANAGEMENT

Out of the environmental management games reviewed in chapter 2, Irrigania (Seibert & Vis, 2012) was chosen as a suitable tool for collecting information on real-agents within a virtual environment. Irrigania was chosen because it is accessible online and enables interaction between players.

In sections 3.1 and 3.2 of this chapter, a literature review is provided for CPRs and institutional arrangements. Next, the tools used for teaching sustainable natural resource management and collecting information about players decisions and behavior are presented in sections 3.3. Finally, the results and discussion are given in section 3.4.

3.1 Common-Pool Resources

Rivalrous and excludable natural and manmade resources are defined as CPRs; examples include fisheries, forests, groundwater basins and irrigation systems (Agrawal, 2003). CPRs’ are distinguished by their openness to exploitation and susceptibility to degradation, causing what Hardin (1968) coined "the tragedy of the commons." In such a case, all rational beneficiaries act to maximize their own benefits by extracting resources without regard to the health of the system and in doing so deplete resources and decrease long-term benefits of all users. Gardner, Ostrom and Walker (1990) refer to this situation as a "CPR dilemma," defining four conditions that are required for it to result: resource unit subtractability, multiple appropriators, suboptimal outcomes and constitutionally feasible alternatives.

A reasonable framework for explaining tragedy of the commons is the Prisoner's Dilemma game (Gardner, Ostrom, & Walker, 1990; Madani, 2010), in which individualistic
rational behavior results in a Pareto inferior solution for all parties as a result of uncertainty and non-cooperative strategy. Hardin concluded that centralized government and private property are the long-term solutions for preventing tragedy of the commons. However, studies in game theory and works including those by Ostrom (Ostrom, 1986; Gardner, Ostrom, & Walker, 1990; Dietz, Ostrom, & Walker, 1990), Wade (1987), and Baland and Platteau (1999), and Madani and Dinar (2011; 2011; 2012) find that such a tragic outcome are not necessarily the case and that factors and institutions exist that can reduce or prevent overexploitation of CPRs.

Scholarship on the characteristics that improve the likelihood of sustainable CPRs is well documented. An analysis by Agrawal (2003) found 24 different factors (possibly as many as 30-40) critical to the organization, adaptability, and sustainability of a common property, see Table 3. These factors were then broken down into groups: resource system, group, institutional arrangements, and external environment characteristics. Of these, Irrigania allows for the study of group and institutional arrangement characteristics, such as how (1) resource monitoring, (2) information disclosure, (3) appropriate leadership, (4) social capital, (5) support of effective rule enforcement, and (6) group size affect the CPR sustainability. Using Irrigania as a virtual CPR environment and changing settings associated with these characteristics can provide an environment to analyze different factors, individually or in combination, affecting decision-making and behavior.
Table 3. Critical enabling conditions for sustainability on the commons

1. Resource system characteristics
   i. Small size (RW)
   ii. Well-defined boundaries (RW, EO)
   iii. Low levels of mobility
   iv. Possibilities of storage of benefits from the resource
   v. Predictability

2. Group characteristics
   i. Small size (RW, B&P)
   ii. Clearly defined boundaries (RW, EO)
   iii. Shared norms (B&P)
   iv. Past successful experiences-social (RW, B&P)
   v. Appropriate leadership-young, familiar with changing external environments, connected to local traditional elite (B&P)
   vi. Interdependence among group members (RW, B&P)
   vii. Heterogeneity of endowments, homogeneity of identities and interests (B&P)
   viii. Low levels of poverty

(1 and 2) Relationship between resource system characteristics and group characteristics
   i. Overlap between user-group residential location and resource location (RW, B&P)
   ii. High levels of dependence by group members on resource system (RW)
   iii. Fairness in allocation of benefits from common resources (B&P)
   iv. Low levels of user demand
   v. Gradual change in levels of demand

3. Institutional arrangements
   i. Rules are simple and easy to understand (B&P)
   ii. Locally devised access and management rules (RW, EO, B&P)
   iii. Ease in enforcement of rules (RW, EO, B&P)
   iv. Graduated sanctions (RW, EO)
   v. Availability of low-cost adjudication (EO)
   vi. Accountability of monitors and other officials to users (EO, B&P)

4. External environment
   i. Technology
      a. Low-cost exclusion technology (RW)
      b. Time for adaptation to new technologies related to the commons
   ii. Low levels of articulation with external markets
   iii. Gradual change in articulation with external markets
   iv. State
      a. Central governments should not undermine local authority (RW, EO)
      b. Supportive external sanctioning institutions (B&P)
      c. Appropriate levels of external aid to compensate local users for conversation activities (B&P)
      d. Nested levels of appropriation, provision, enforcement, governance (EO)


Source: Agrawal (2003)
Managing CPRs is difficult because of their complexity, dynamics and specific circumstances. The institutional arrangements (structures of rules) associated with CPRs are important to resource sustainability and have been a major topic in research. The characteristics of institutional arrangements can vary enormously, but typically include policies, systems and processes that provide beneficiaries with options for monitoring, sanctions, adjudication and accountability (Agrawal, 2003). The general framework for analyzing institutional arrangements is shown in Figure 4. The first column contains the contextual attributes of the resource: (1) physical attributes or the resource; (2) attributes of the resources' community (beneficiaries); and (3) the institutional arrangements used. The action situation is dependent on the nature of the previous three variables and changes to them can lead to very different outcomes (Ostrom, 1986). The incentives and interaction between beneficiaries also affects the outcome of the situation. When it comes to policy implications, institutional arrangements offer the greatest opportunity to induce change in beneficiaries’ behavior and affect outcomes.

Figure 4. Framework for institutional arrangement analysis

Source: Adapted from Tang (1991)
Madani and Dinar categorize the major CPR governance frameworks as non-cooperative, exogenous, and cooperative management institutions (Madani & Dinar, 2011; Madani & Dinar, 2011; Madani & Dinar, 2012). In their study, non-cooperative institutions include: ignorant myopic, smart myopic, fixed ignorant non-myopic, variable ignorant non-myopic, and smart non-myopic management of resources on a non-cooperative basis (without any interaction). These institutions categorize CPR beneficiaries based on their levels of myopia, foresight into the future and willingness to long-term planning, and smartness or attention to the externalities, ranging from an ignorant player who fully ignores the externalities to smart players who try to estimate the externalities through heuristic learning. The result of non-cooperative institutions is low payoff for beneficiaries ranging from the worst in ignorant myopic, to the best in smart non-myopic. Ignorant myopic management, as in tragedy of the commons, exhausts resources quickly, while the smart non-myopic users implement coordinated strategies that result from developing heuristic management plans based on learning from previous behavior and plan long-term (Madani & Dinar, 2012). Exogenous regulatory institutions, including quota, status, tax and bankruptcy based management institutions, can also be used by regulators to sustain CPRs, but are only effective when fully enforced and followed by beneficiaries (Madani & Dinar, 2011). Quota-based and status-based management have been found to be successful institutions for prolonging a CPR’s life and increasing the benefits to its beneficiaries who might have different behavioral characteristics. Tax-based management institutions, however, might not effectively improve the beneficiaries payoffs and CPR’s life, but could be used in combination with another exogenous regulatory institution, as tax-based management allows for collecting funds to enforce rules. Lastly, cooperative management institutions based on group rationality can be used for
sustainable CPR management. These institutions have been shown to prolong the life of a CPR and improve beneficiaries’ payoffs, but could be difficult to implement (Madani & Dinar, 2011).

3.3 Methodology

3.3.1 Irrigania

Irigania (Seibert & Vis, 2012) is a web-based water conflict game used as a tool to analyze CPR characteristics, collect information and facilitate better understanding of institutions and externalities associated with governance and management of CPRs. In Irrigania, students play as farmers sharing a water resource system used for irrigation. Multiple games were played, each with different settings, to represent varying institutions and characteristics that have been shown to benefit the long-term use of CPRs. After each game, patterns observed in users’ techniques and behaviors were discussed to investigate the causal links between behavior, settings and results. Although Irrigania is a simplified model for sharing a CPR, the behavior and actions of players can provide valuable insights into the investigation of underlying factors affecting beneficiaries’ exploitation of the system, along with policy and management techniques to promote sustainability.

Irigania is a role-playing game in which users play as farmers within a village. Each village contains farmers and is a part of a larger "village cluster." Each farmer chooses his own irrigation scheme consisting of river water, groundwater, and rainwater to use on the ten fields that each farmer possesses. Decisions are made every round (year) until the game finishes at a preselected year by the game moderator (course instructor in this case). Different costs and profits exist for each source of water; riverwater and rainfed irrigation supplies have a fixed cost,
while the revenue for riverwater is dependent on precipitation and number of fields using rainwater. On the other hand, the cost of using groundwater varies with respect to the depth of groundwater, but has a fixed return on each field it is used on. The maximum profit per field for using groundwater, riverwater, and rainwater is 80, 80, and 25 units, for normal (constant) precipitation, making the first two sources preferable for quick profit. In the game, groundwater has a carry-over effect from year to year and is dependent on the amount of precipitation for recharge and exploitation by users, while river water is independent of prior years, changing only in response to precipitation and water use of the current year. For example, if groundwater is pumped heavily in year 1 and the groundwater table drops to 9 units, in the following year groundwater level will begin at 9 units and changes relative to its use and recharge for year 2. In Irrigania, groundwater and river water are not hydraulically connected. In our experiment, the students were told that their Irrigania assignment grade will be based on their profit. Therefore, the objective of the game is to be either the most profitable farmer or the best village in the village cluster by the end of the game.

3.3.1.1 Settings

The settings of Irrigania can be adjusted each game to represent different game environments to analyze the effects of players' decision-making and behavior. The game's settings can be accessed on the Irrigania website: http://www.irrigania.ch by logging into the "Teacher" section. Access is free and available by contacting its authors. Once logged in, three options are available: setup village clusters, follow the status of a village cluster, and edit teacher settings. Under the edit teacher settings section, the default number of villages per cluster and farmers per
village can be changed. Setting these values to your intended size can save time, instead of manually adding and deleting village clusters and farmers in the setup village clusters section.

The next step is to make changes to the individual game settings by going to the setup village clusters section, shown in Figure 5. The left panel displays the structure of each village cluster, including the number of villages and farmers each contains. The quantity of any of the village clusters, villages or farmers can be increased by clicking on the heading containing the element that needs to be changed and selecting add or decreased by selecting the element itself and selecting delete at the bottom of the page. For example, if the number of farmers in Village_1 of Figure 5 needs to be changed from five to six, the teacher can click on Village_1 then press add to create Farmer_6. To delete Farmer_6, the teacher would simply select Farmer_6 and press delete. In addition to modifying the structure of each village cluster, there are settings that can be altered for village clusters and changes that can be made to villages and farmers. By clicking on a village cluster its settings open in the right panel. At this point, modifications can be made to the village cluster name, length of game (years), rainfall condition, and information disclosure. The rainfall condition, which affects the profit of groundwater, riverwater and rainfed irrigation according to Figure 6 has two options, normal or random. For normal rainfall, \( P = 1 \) for every year, while random rainfall changes randomly between \( P = 0, 1 \) and 2 each year. Teachers can also change whether each farmers’ inputs (irrigation scheme) can be seen by the other farmers in the same village. Choosing to show farmer inputs enables all villagers to view each other's irrigation scheme in the Villages and Users box shown in Figure 8. This display shows: "Farmer Name (Status) (Groundwater - Riverwater - Rainfed)". For example, Farmer_1 (Irrigating) (2-3-5) shows that Farmer_1 is now Irrigating (logged in, but has
not submitted the current years irrigation scheme) and that his previous years decisions were irrigating two fields with groundwater, three with riverwater and five with rainfed irrigation. If show input farmers is not selected, only "Farmer Name (Status)" is shown. Similarly to the village clusters, clicking on a village or farmer in the left panel opens the right panel and allows the teacher to change the name of the village and farmer, in addition to logging a farmer out of the game. This is an important feature because Irrigania does not automatically logout players once they leave the Irrigania website. Therefore if a player does not manually logout before leaving the site, they will receive an error message explaining that their account is already logged in when trying to access it the next time. The logout farmer button allows the teacher to manually logoff a student to enable them to login. The last section for teachers to use is follow the status of a village cluster, which allows them to view the progress of a game or its final results, shown in Table 4. Since using Irrigania for this study, this section of Irrigania has also been updated and now include graphs for rainfall conditions, groundwater level per village, river irrigation reduction factor per village, farming decisions per farmer, average farming decisions per village, balance per farmer, average balance per village and accumulated balance per farmer.
Figure 5: Setup village cluster section
Source: www.irrigania.ch (screenshot)

<table>
<thead>
<tr>
<th>Type of water supply for field</th>
<th>Cost per field</th>
<th>Revenue per field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed</td>
<td>5</td>
<td>30 (in normal year) 10 (in dry year) 40 (in wet year)</td>
</tr>
<tr>
<td>Irrigation with river water</td>
<td>20</td>
<td>100 k with k=min $1 - \frac{\text{Fr}}{10 - (1.5 + P)}$</td>
</tr>
<tr>
<td>Irrigation with groundwater</td>
<td>$g \leq 8 : 20 \geq 8 : 20 + (g - 8)^2$</td>
<td>100</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>$F_{river}$</td>
<td>Number of fields with river water irrigation</td>
</tr>
<tr>
<td>$F_{gw}$</td>
<td>Number of fields with groundwater irrigation</td>
</tr>
<tr>
<td>$g$</td>
<td>Depth to groundwater</td>
</tr>
<tr>
<td>$n$</td>
<td>Number of farmers in a village</td>
</tr>
<tr>
<td>$P$</td>
<td>Precipitation indicator (normal year: 1; dry year: 0; wet year: 2)</td>
</tr>
</tbody>
</table>

Figure 6: Water supply cost, revenue and variables
Source: www.irrigania.ch (screenshot)
3.3.1.2 Game Interface

After going to the website (www.Irrigania.ch) and logging-in by entering teacher, village cluster, village and farmer name, students are directed to Irrigania’s game interface, see Figure 8. The interface is simple and straight forward, containing all information needed to play the game on a single page, including farming decisions, economical status, current hydrological conditions and the villages and users box. In the farming decisions area, the player inputs their choices for the how many fields to irrigate with groundwater and riverwater, and the rainfed irrigation value adjusts so that the total number of fields is equal to 10. Once the player is finished with this step, he or she presses submit and waits for the other farmers to do the same. After everyone has submitted their decisions, the screen updates and the year at the top of the screen displays the following year. The economic status of the player and the hydrological conditions of the village also updates each year. The economic status displays the player's balance for the previous year and their accumulated balance. The hydrological conditions area reveals the current depth to groundwater, the cost of using groundwater per field for the previous year, precipitation condition of the previous year and the river irrigation reduction factor (K from Figure 6). The final area of the page, villages and users, displays each farmer's status and profit (in the new version), in addition to irrigation scheme depending on the games rules. Combined, this information provides the basis for students to decision making.
3.3.1.3 Playing Irrigania

Before each game of Irrigania was played, a document, Irrigania Procedures, containing relevant information and procedures for the upcoming game were sent to students. An example of this document can be found in Appendix A - Figure 33. The first page of the document contains a brief summary of Irrigania and the cost and revenue information associated with the sources of irrigation available in the game. The next section of this page describes the objective (maximum farmer or village profit) and rules (communication, precipitation, length of game and information disclosure) for the particular game at hand. The next page gives a short explanation of how to login into Irrigania and an overview of the user interface. The third page provides students the
information they need to login, village cluster and village name; each students' name was used as the farmer name. The final page gave the schedule for completing each game of Irrigania.

![Irrigania Student User Interface](https://www.irrigania.ch/screenshot)

**Figure 8**: Irrigania student user interface

Source: www.irrigania.ch (screenshot)

After logging in, the gameplay itself is quite straightforward. Each student in a village enters his irrigation scheme for the current year and then waits for each farmer to do the same. When every farmer has submitted the current year’s irrigation scheme, the title at the top of the screen switches to the next year. At this time, the hydrological and economical information and the player’s balance are updated. The student then records relevant information (explained next
section). This process continues until the predetermined number of years is reached, at which point a table of each farmers' accumulated profit is displayed.

3.3.1.4 Data

In Irrigania, data regarding each players' or villagers' annual irrigation scheme, profit or hydrological information could not be accessed from the website directly. Only a player’s final accumulated profit could be obtained through the teachers account and even this information was only available for a few days until the data was removed online. Each players' annual balance in the villagers and users box, Figure 8, was also not available at the time Irrigania was used. Therefore, an important task given to students participating in the game was to record their decisions regarding irrigation scheme and yearly balance for each year. For games that included the option to cooperate, students were also asked to write whether they did or did not cooperate with those in their village. After the game was finished, students were asked to turn in their Irrigania Data Sheets by email. The data was then transferred to a spreadsheet for analysis. An example of the Irrigania Data Sheet is shown in Appendix A - Figure 34.

3.3.1.5 Settings of Games Played

Six games were designed to analyze the effects and decision making that the different settings in Irrigania elicit. The games were constructed to simulate different institutions by changing communication, precipitation, game length, information disclosure and goal of the each game. Additionally, games were setup to isolate an individual setting to compare the results of two similar games. The commonality of each game (excluding UCFU) was that students were randomly assigned to a village for each game. This provides two purposes, to prevent players from becoming familiar with each other’s strategies and to promote interaction and
communication between as many students as possible. The six different games are described below, followed by Table 4, which provides a summary of the settings.

Game Framework 1: Non-cooperative with Constant Variables

The first game is the most basic or all games. It consists of 15 rounds, uses constant precipitation and does not allow communication between players. In addition, information about player’s decisions are not shown, which in combination with no communication prevents any sort of negotiated water regulation. The objective was for players to experience the non-cooperative CPR management environment.

Game Framework 2: Cooperative with Constant Variables

The next game followed the same settings as the previous, except communication was allowed, but not mandatory. In this case, players could decide if they wanted to communicate with the others to strategize, but were not obligated to keep their promises by a predefined penalties. The objective was to allow players to experience the benefits of cooperation (increased profit), but to also recognize the difficulties associated with it (free-riding, cheap talk, etc).

Game Framework 3: Community Rationality with Constant Variables

In the third game, the goal of the game was changed from being the most profitable farmer to the most profitable village. The settings remained the same as Game Framework 2, except in-game information disclosure (competing player’s irrigation scheme) was now available. The incentive to outperform the players in one’s own village is essentially eliminated by switching to the goal highest village profit. The result is expected to be similar to that of a social planner. The purpose of information disclosure was to allow players to monitor each other’s irrigation scheme and...
work together to make adjustments. The objective of this framework was to examine how decision-making based on a group rationality as opposed to individual rationality would affect players.

Game Framework 4: Non-cooperative with Random Variables and Information

The fourth game framework was the first in which players were introduced to random precipitation and unknown game length. The settings prohibit players from communicating with each other directly, but does allow them to view each other’s irrigation scheme during each round. In this way, the uncertainty associated with no communication could be lessened if students decided independently to irrigate in a sustainable manner and could observe rival farmers irrigating in a similar fashion. However the opposite is also true; if players observe another student irrigating heavily with riverwater and/or groundwater it could cause them to stop irrigating sustainably and switch to the more profitable riverwater and groundwater.

Game Framework 5: Cooperative with Random Variables and Information Disclosure

The progression from game 4 to 5 is similar to that of game 1 and 2. Settings remain the same as the previous game (random precipitation, unknown game length and in-game information disclosure provided), except communication was now allowed between players. This game can be compared with both games 2 and game 4 to determine the effect that uncertainties have on cooperation and how cooperation and information disclosure effect the decision making of players, respectively.
Game Framework 6: Non-cooperative with Random Variables

In the final game of Irrigania, the game settings were once again changed to prohibit communication between players. Game Framework 6 involves the most uncertainty for players, non-cooperative, no monitoring and random variables, and is likely to result in a commons dilemma. Presenting players to once again participate in a non-cooperative institution allows observation on whether the knowledge gained from previous games enables players to escape the pitfalls associated with no communication.

Table 4. Game frameworks for Irrigania

<table>
<thead>
<tr>
<th>Settings</th>
<th>Game 1</th>
<th>Game 2</th>
<th>Game 3</th>
<th>Game 4</th>
<th>Game 5</th>
<th>Game 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>Communication allowed?</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Precipitation</td>
<td>Constant</td>
<td>Constant</td>
<td>Constant</td>
<td>Random</td>
<td>Random</td>
<td>Random</td>
</tr>
<tr>
<td>In-game information disclosure</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Game length</td>
<td>15</td>
<td>15</td>
<td>15</td>
<td>Unknown</td>
<td>Unknown</td>
<td>Unknown</td>
</tr>
<tr>
<td>Profit maximization</td>
<td>Individual</td>
<td>Individual</td>
<td>Village</td>
<td>Individual</td>
<td>Individual</td>
<td>Individual</td>
</tr>
</tbody>
</table>

3.3.2 Facebook

The social media websites Facebook was used as a channel for informal communication between due to its wide-use among students. A Facebook group was created and named “Water Policy, Planning and Management” for the two main purposes, using Facebook as a site for posting and discussing current news events and for communicating information and results for Irrigania. Facebook coincides well with the social constructivist learning orientation, providing a collaborative environment that lets students help each other out, lend support and interact with
one another (Kelm, 2011). It has also been found to have a robust connection to indicators of social capital, particularly bridging social capital (Ellison, Steinfield, & Lampe, 2007). This suggests that using Facebook has potential to support students' development of social ties, which could improve the class's interaction and involvement, which could be especially helpful for online students. While Facebook was used for disseminating the rankings of games, other media was also used for students to communicate, including various email and video chat programs.

3.3.3 WaterSISWEB

The final tool used in this approach to teach about water resource concepts is WaterSISWEB (www.siswebs.org/water), the first website of the SISWEBS (Scientific Information Syndication WEBstieS) family, dedicated to water resources engineering and management (About WaterSISWEB, 2013). WaterSISWEB is a social bookmarking website that allows registered users to share news, articles, papers, videos, or photos related to water resource. A screenshot of the WaterSISWEB homepage is shown in Figure 9. New submissions are posted in a tab for “upcoming” posts, where other users can vote and comment on posts. Once a post receives enough votes based on a user-based ranking system, the post is then moved to WaterSISWEB’s home screen on the “top” posts tab. In this way, WaterSISWEB gives users democratic editorial control over its top published posts. WaterSISWEB also provides features for users to search for by posts by keywords, category, link type and region. Additionally, a tag cloud (figure that displays a cluster of keywords with the most popular keywords in larger font than less popular keywords) on the home page to provide a visual display of the most popular topics for users.

The purpose of using WaterSISWEB was to provide a formal forum for students to share information related to classroom discussions about sustainable management of natural resources.
Students can connect current news and posted media with classroom concepts as they refine their understanding of the practical challenges associated with developing effective policies and management institutions for sustainable resource management.

![WaterSISWEB home screen](image)

**Figure 9:** WaterSISWEB home screen  
Source: www.siswebs.org/water (screenshot)

### 3.3.4 Participants

During this study, three different groups participated in Irrigania: (1) graduate water resources course for Water Policy, Planning and Governance at UCF; (2) graduate course for Environment
and Sustainable Development in the Middle East at Lund University, Switzerland; and (3) undergraduate Water Resources II course at UCF. Each of these sessions incorporated different elements into the game experience such as location of play (home, in class, and in computer lab), use of social media and the amount of time each group used the game. However, the settings of each individual game were kept the same to compare the difference between the groups. Groups 1 (UCF graduate) and 2 (Lund graduate) performed all of the games 1-6 and group 2 played games 1-3. A description of each group that participated in Irrigania and an explanation of the six games follows.

3.3.4.1 Group 1: Graduate UCF

The first group of students to participate in using Irrigania was a graduate class at the University of Central Florida, enrolled in a course for Water Policy, Planning and Governance. This group (hereafter referred to as UCFG) consisted of 28 students participating as both traditional in-class and strictly online students seeking degrees in water resource, civil, environmental or industrial engineering. Irrigania was introduced to students early in the semester.

Students were emailed the Irrigania Procedures sheet containing login information (village cluster, village and farmer name) and a schedule for completing the game. At this point it was considered each village’s responsibility to contact each other to establish a playing time and to strategize if the game allowed communication. The amount of time students were given to complete each game of Irrigania varied. For game one, which lasted 15 rounds, students played two rounds each night and three games on the seventh night. The slow pace was to allow students, who were new to the game, to take their time and observe how different decisions changed the results of the game. At the end of each day, the updated balance for each player was
posted to Facebook as a way to provide feedback for students. As players became familiar with how to play the game, the number of rounds played per game increased to the point where an entire game was completed in one sitting. In addition to playing Irrigania and using Facebook for posting results, both Facebook and WaterSISWEB were also used for posting news, articles and videos related to the course.

3.3.4.2 Group 2: Graduate Lund

In the second installment of Irrigaina, graduate students enrolled in a course for “Environment and sustainable development in the Middle East” at Lund University (hereafter referred to as LU) were the players. Unlike the graduate students at UCF, those at LU were not engineering majors. The course covered topics including water resource management, hydropolitics and sustainable management of the commons, subject areas that can draw on experiences in Irrigaina and invite conversation.

Irrigaina at LU was played in a series of three classes that lasted approximately 2 hours and 30 minutes. Because the class was relatively small (at most 11 students) and every student owned or had access to a laptop, students brought their laptops to class to play Irrigania. Similarly to UCFG, those at LU had also been taught about CPRs and tragedy of the commons prior to playing Irrigania. Two games were played each meeting for a total of six games. Because the class was so small, there were only 3 villages used per game containing three to four farmers. As was the case with the UCFG, each student was randomly assigned to a village for each game to insure that students were able to experience different scenarios caused by unique behavior of each player. LU did not use Facebook or WaterSISWEB while using Irrigania because gameplay took place quickly and in the classroom, but students were invited to join nonetheless.
In addition to studying the behavior and decisions of players under different institutions as done with UCFG, it was of interest to observe how the differences in implementation and time using Irrigania between UCFG and LU would affect the outcomes. The two most significant changes were playing face-to-face versus playing online and the difference in time spent using Irrigania, now three classes instead of the majority of a semester.

3.3.4.3 Group 3: Undergraduate UCF

The final groups of students to participate in using Irrigania were undergraduates enrolled in Water Resources II, a course including material from hydrology and hydraulics. Two lab groups for one class of UCF undergraduates (hereafter referred to as UCFU) participated in using Irrigania (each session contained 18 students). The lab sessions lasted approximately 1.5 hours, so only 3 of the 6 institutional frameworks (explained in the next section) were played by students. Additionally, the Facebook group and WaterSISWEB were not introduced to UCFC because all three games were completed in one setting. Students were sent the Irrigania Procedure and spreadsheet two days before the lab session to allow them to become familiar with the game. At the start of the lab session a brief lecture was given on CPRs, CPR institutions and tragedy of the commons to provide background on the purpose of the game. Also, because time and space were limited in the computer lab, the students in each village did not rotate groups from game to game as did UCFG or LU. The results of each game (students' ranking) were displayed on the board following completion and students were given a few minutes to discuss the results with their group. Two game moderators surveyed the discussions and asked the each group questions about how game settings (communication, information disclosure, etc.) and players’ behavior (trust, cheating, etc.) affected the game’s outcome to promote debate. After the
three games of Irrigania were completed, students were given laboratory homework to write a reflection paper on what they learned about CPRs and their thoughts about Irrigania. UCFU did not use Facebook or WaterSISWEB.

3.3.5 Analysis Techniques

3.3.5.1 Quantitative Results

To make inferences about results of participants profit means associated with different games and groups, One-Way ANOVA (ANalysis Of VAriance) procedures will be utilized. The One-Way ANOVA procedure produces a one-way analysis of variance for a dependent variable (accumulated average balance) by an independent factor (group or game). The function is to assess whether the treatment (games) means differ by comparing the variation between the samples to the variation within the samples. The null hypothesis for One-Way ANOVA is that the variance of sample means is the same, whereas the alternative hypothesis is that the difference in samples variance is not equal.

\[
F = \frac{\sum_{i=1}^{k} n_i (Y_i - \bar{Y})^2}{(k - 1)} = \frac{SS(Tr) / (k - 1)}{SSE / (N - k)}
\]

where: \( F \) is the F-statistic; \( Y \) is the variate; \( k \) is the number of treatment groups; \( n \) is the number of samples within each treatment group; \( N \) is the total number of samples in all treatment groups; \( j \) and \( i \) are denoted as \( j \) th observation in the \( i \) th sample of the variate; \( SS(Tr) \) is the treatment sum of squares; and \( SSE \) is the error sum of squares.

Assumptions for One-Way ANOVA procedures are that (1) all the \( k \) population probability distributions corresponding to the \( k \) treatments are normal and (2) the population variances of the
k treatments are equal. To test these assumptions the following plots are included with the ANOVA: histogram or residuals, normal plot of residuals, residuals versus fits, and residuals versus order. Although the majority of the data is expected to be normally distributed, settings involving communication could skew the distribution, making it non-normal. However, the AVONA test is said to be "robust" to violations of normality assumptions and even data that deviates from normality will result in correct conclusions about the null hypothesis.

Tukey's method was employed with One-Way ANOVA testing to further investigate which game frameworks resulted in similar or different outcomes. Tukey's method is used to create confidence intervals for all pairwise differences between treatment group means while controlling the error rate to a specified level, here $\alpha = 0.05$. Tukey's method adjusts ($\alpha_{\text{adj}} < \alpha$) the error rate for each pairwise comparison to reduce the chance of making a type 1 error because the chance of a series of comparisons is greater than only one comparison between all treatments. The results of Tukey's method are a set of confidence intervals of the difference between each of the treatment' mean. Treatments are sorted into one or more groups based on the outcome of the previous step, those within the same group are considered statistically equal while those within different groups are not. The groups are output as letters, with values increasing alphabetically (e.g. treatments in group A have a significantly larger mean than group B.)

3.3.5.2 Empirical Results

In addition to analyzing students profits from using Irrigania, there is also a need to determine what factors not subject to numerical results effected CPR management and also students' learning outcomes. Intended learning outcomes and skill acquisition, such as "deep" understanding, critical thinking, teamwork, etc., cannot always be reliably tested, therefore
empirical analysis of participants’ discussions and reflection papers will be provided in Chapter 5: Discussion. This empirical evidence will be combined with the quantitative results to best explain both of these areas.

3.4 Results and Discussion

3.4.1 Graduate UCF

An important aspect of the Irrigania experience was the class discussions initiated between different games. The following comments were discussed during these conversations. Additionally, the data students recorded for each game, such as irrigation scheme or level of cooperation is also analyzed here. For each game, the annual village profit, annual irrigation scheme, ANOVA results and accompanying information is either given in the following section or provided in Appendix B.

3.4.1.1 Game Framework 1

The first game of Irrigania resulted in rapid exploitation of groundwater, before reaching a stable level associated with little profit. The game began with heavy use of the more profitable groundwater and river water, but as the profit for groundwater began to drop below 25 ft (profit of rainfed irrigation), students began to reduce groundwater and increase rainwater. This behavior resembled the smart myopic user (Madani & Dinar, 2012); characterized by heuristic learning about externalities and short-term planning. Figure 10 illustrates this point by showing the relationship between the average annual profit of all villages and the average depth to groundwater, representative of overuse of the resource. The first observation was that in three of the five villages (one village was excluded for insufficient data), one or two members were
ranked high (high profit), while the rest were below average. Village A contained the most profitable farmer of all the villages, earning $7699 ($513/yr). However, village A's average profit was only $5474 ($365/yr), ranking them third overall out of the five villages; the other three farmers in village A ranked 10, 27, and 28 out of the 28 students in the class. The accumulated balance for each village in for this game can be found in Figure 11. The other two villages that followed this pattern were villages 2 and 4. Village C was one of the groups with differing results, containing no farmers ranked in the top half of the class. All villages, excluding village 3, tried to incorporate more rainwater into their irrigation scheme once groundwater was not profitable. Members of village C recognized the need to incorporate more rainwater, but were unwilling to move away from groundwater and riverwater. These students presumed that if they were to increase their proportion of rainwater, other villagers might free-ride by continuing to use high levels of groundwater and riverwater. Instead of taking on the risk associated with this scenario, village C continued to defer using rainwater even if it meant lower earnings than other villages. The other village that deviated from one farmer profiting at the expense of the other villagers was village 5, which finished with all farmers ranked in the top half of the class. In addition, village 5 used the highest percentage of rainwater (45.6%) compared to any of the other villages, which caused groundwater and riverwater to remain profitable for a longer period of time, resulting in the highest average village profit ($5930 or $395/yr) in game 1. The level of uncertainty associated with the non-cooperative institution of game 1, led students to depreciate the value of maintaining a sustainable system. These findings were supported by the data in Table 5, which shows a correlation with average village profit and percent of rainfed irrigation. The villages relying heavily on groundwater and river water were less profitable than the villages using a higher percentage of rainwater over the length of the game. The main lessons that
students took away from game 1 included the externalities associated with a CPR system, the long-term consequences of a myopic mentality, and the behaviors of beneficiaries faced with uncertain information.

Figure 10. Smart myopic behavior: UCFG – Game 1

Figure 11. Accumulated village profits: UCFG – Game 1
3.4.1.2 Game Framework 2

The second game of Irrigania allowed farmers to communicate with each other to develop strategies to increase profit. Communication was voluntary and farmers that deviated from an agreed upon strategy were not penalized, aside from the dismay of fellow farmers. Game 2 resulted in varying levels of cooperation among the villages. Villages C and D cooperated 100% of the time, while farmers in villages A, B, E, and F cooperated 75, 75, 85, and 55% of the rounds. Cooperation levels were determined by students recording whether they did or did not cooperate for each round; the average cooperation for each village was calculated per round and over the entire game. From the profits in Figure 12, it can be seen that higher levels of cooperation are associated with higher profits. Village F, which had the lowest percentage of cooperation and second lowest average farmer profit ($5205 or $347/yr), could not reach a consensus on whether to cooperate or work alone at the beginning of the game. As a result, the students that initially wanted to cooperate decided to work alone and use the groundwater and riverwater more; rainwater was used for 16.8% of fields from year 1-5 and 32.0% from year 6-15. Students realized that such an irrigation scheme was not sustainable from playing game 1, but presumed that the students that did not want to cooperate had planned to utilize the groundwater and riverwater heavily, instead of a sustainable scheme that incorporated rainwater. By the end of year 6, village F realized that their yearly and accumulated balance was decreasing faster than the other villages; in response village F began to cooperate, but were unable to overcome the low profits resulting from overusing groundwater by the end of the game. Village F finished the game with students ranking 20, 22, 23, 26, and 27 out of 28 students.
Askew why the farmers in fully cooperative villages did not deviate from their plan, students responded that they felt morally obligated to continue to cooperate once they realized that the rest of their village was also cooperating. Because villages chose to cooperate and kept that promise throughout the game, students were satisfied with having the same profit as their teammates. For those in partially-cooperative villages, the reason for taking more than an agreed upon amount was because another villager had already deviated from the plan. In response to the diversion, farmers that were cooperating previously felt compelled to cheat in order to offset the deficit created by the first farmer that exploited the village. An aspect of game 2 not mentioned in the class discussion was the behavior of players in villages with partial cooperation at the end of the game. Figure 13 shows the level of cooperation in villages A, B, and E varied from years 1-12, but all decreased in the final three years. Game 2 was played 3 rounds each time, therefore round 13-15 was the final night of playing game 2; because players would not be able to react if another farmer deviated from the plan (no chance for tit-for-tat), many students took this opportunity to try and boost their profit. Village 6, which initially played uncooperatively, was the only partially-cooperating village that increased cooperation in the final three years; as they were still recovering from overexploiting groundwater earlier in the game and were cooperating in an effort to increase profit. An observation was that villages that cooperated for the majority of the time, even those that finished only slightly better than average, were content with their strategy and would choose to cooperate again in a future game. The social capital that was built from these groups seemed to increase resiliency even under suboptimal outcomes. Although the irrigation scheme for each user was not displayed on Irrigania between each round, posting the accumulated profits every third round allowed students to speculate on the water use of other farmers and the level of cooperation. Disclosing profits allowed students to adjust their strategy.
during the previous non-cooperative game and adapt their group strategy if cheating was detected during a cooperative strategy. This led to students requesting to play fewer rounds per day to allow for increased monitoring.

Figure 12. Accumulated village profits: UCFG – Game 2

Figure 13. Cooperation in partially cooperating villages: UCFG – Game 2
3.4.1.3 Game Framework 3

In the third game, the individualistic mentality that was associated with diverting from a cooperative strategy in the previous game was removed by changing the objective from being the most profitable farmer to the most profitable village. All villages agreed that cooperating was the best course of action, developing a group strategy to maximize profit. The accumulated profit for each village can be seen in Figure 15. The difference in profit between the villages was a matter of strategy, the top two villages, A and E, cut back on groundwater for a few rounds, while the other villages maintained a fairly consistent strategy, see Figure 15. As the game approached year 15, the profit disparity from groundwater enabled village A and E to increase yearly balance over the final few years, while the balance of villages B and F decreased. Two villages, B and C, chose to use groundwater on a larger percentage of their fields in the first two years and ended finishing with the bottom two ranks. Village 3 attempted to let the groundwater recharge, but could not increase profits enough by year 15. All villages used groundwater heavily the final years to boost profits. From this game, students recognized the benefits of long-term collective action. The average profit per farmer was $7299 ($487/yr), a 16.4% increase from game B and a 33.0% increase from game A. Students also discovered that conjunctive water use strategies, such as recharging groundwater to increase long-term profits, were valuable.
Figure 14. Accumulated village profits: UCFG – Game 3

Figure 15. Annual village balance: UCFG – Game 3
3.4.1.4 Game Framework 4

Students were introduced to random precipitation and unknown game length in game 4. Similarly to game 1, communication was not allowed, but students could now monitor the irrigation scheme of each farmer. In the first year, groundwater was used for 50% of irrigation in year 1, an increase from game 1 (41%), game 2 (43%) and game 3 (25%), see APPENDIX B: UCF GRADUATE. At the same time, the proportion of rainfed irrigation was 32%, lower than games 2 (40%) and 3 (46%) and equal to game 1 (32%). The average balance for game 4 was $377/yr. Because each village played Irrigania for a different number of years, an average balance is more appropriate to compare students' profit to other games than the average profit for each player. Of the five villages, only village E's average balance was significantly different than the rest, see Figure 16. This group contained four farmers, three of which were determined to claim riverwater for the majority of their irrigation needs. As the game went on, the farmers continued to use primarily riverwater even though it was the least profitable source of water, see Figure 17. This group was reluctant to use rainfed irrigation for themselves and allow another farmer to earn more than them, by the end of the game the three competing farmers averaged less than one field of rainfed irrigation between them, the game average was over 3 rainfed fields per farmer. The three farmers continued this strategy until the game ended (years = 19) and village E averaged only $259/yr.
Figure 16. Accumulated village profits: UCFG – Game 4

Figure 17. Irrigation source profit: UCFG – Game 4 – Village E
3.4.1.5 Game Framework 5

Allowing students to communicate and strategized together improved the average balance from game 4 ($377/yr) to $417/yr. Instead of using random game lengths for each of the villages, as in game 4, the same random game length (years = 21) was used for the entire class. However, because the precipitation conditions were still variable between villages direct quantitative comparison between villages may not be appropriate. The average level of cooperation for the game was 66%, including four villages with high cooperation (B, C, E and F), one with no cooperation (A) and one that switched from cooperation to no cooperation (D). The accumulated profit for these villages is shown in Figure 18. It can be seen from this figure that the four cooperating villages finished with a higher average accumulated profit than those that did not cooperate.

![Figure 18. Accumulated village profits: UCFG – Game 5](image-url)
3.4.1.6 Game Framework 6

In the final game of Irrigania with UCFG, the settings were again changed to non-cooperative with random precipitation, but unlike game 4, monitoring was not provided. Players achieved an average balance of $417/yr in game 6, the same balance as game 5. Compared to the other non-cooperative games, the average balance in game 6 was significantly higher than game 1 (P<0.05) and equal to game 4 (P>0.05). The percentage of groundwater used at the beginning of game 6 was in line with prior non-cooperative games using it for 42% and 33% in year 1 and 2. The number of players that initially incorporated rainfed irrigation at the start of game 6 (66%) was actually higher than game 1 (47%) and game 4 (52%). This effort to use more sustainable sources of water at the beginning of the game was echoed by many during the class discussion. In the end players came to the conclusion that the inability to work together and prevent free-riding thwarted any independent effort towards sustainability.

3.4.2 Graduate Lund

For each game, the annual village profit, annual irrigation scheme, ANOVA results and accompanying information is either given in the following section or provided in Appendix C. Additionally, Table 5 provides an overview of information comparing LU, UCFG and UCFU.

3.4.2.1 Game Framework 1

For game 1 of Irrigania with LU, non-cooperative with constant variables, students’ average profit was $5826 ($388/yr) over 15 years of play. Similarly to game 1 of the UCFG, students in LU used primarily groundwater (47%) at the start of the game and then riverwater as the game progressed. Each village’s average balance was fairly consistent, as shown in Figure 19, and as a
result the final profits of village A, B and C were also similar: $5613, $5925 and $5769, respectively.

In game one, students responded similarly to the two other groups by experimenting with irrigation schemes to determine an optimal strategy. The computer of one of the students for game 1 and game 2 (played during same class) ran out of battery; the solution was to allow the student to play as a “two-headed farmer” with another student. The two-headed farmer ended up finishing with the lowest profit by the end of the game. Their explanation for the low score was because of their desire to play fair and not overuse the resources shared by their village. Multiple students expressed a similar viewpoint and felt that environmental factors should have a larger role in Irrigania. At the same time, however, students understood the complexity of resource management involving profit-driven actors or actors with differing objectives in general.

![Game 1: Yearly Balance](chart)

**Figure 19.** Annual village balance: LU – Game 1
3.4.2.2 Game Framework 2

For the second game, students were allowed to communicate and strategize with the farmers in their village. However, no village decided to work together at the start of the game. Although students had been introduced to ideas about tragedy of the commons and sustainability, many still believed that higher profit could be earned by working non-cooperatively by exploiting the high profit resources, groundwater and riverwater, instead of rainwater. In year 3 and 4, village A attempted to work together, but could not reach an agreement and decided to go back to working alone. In year 5, village C also began to cooperate and remained cooperative until year 15, in which two of the three farmers deviated from cooperation to boost their profit. Figure 20 shows the annual balance per village. It can be seen that village C's profit begins to increase relative to village A and B after cooperation begins, finishing with $6246 ($416/yr) versus $5267 ($351/yr) and $5336 ($356/yr), respectively.

At one point during this game, one of the students questioned the objective of Irrigania, asking why she was being taught that cheating and exploiting resources was good. Of course this was not the objective, but it shows that although students can learn about topics like tragedy of the commons and sustainability in class, applying the concepts in a realistic environment may be counterintuitive. By the end of the game this sentiment was beginning to change as village C, which cooperated for much of the game, ended up the clear winner of the game as its' farmers finished ranked 1, 2 and 3 in the class. Lack of trust and inability to detect cheating were two of the primary obstacles hampering cooperation at the beginning of the game. Village C overcame these problems by deciding to sit together and allow other players’ in their village to operate their laptop to eliminate the temptation to cheat and free ride. In this way, students provided their
own monitoring system and believed that it improved trust and social capital within their village. It is interesting, however, that in the final round (year 15) the students ranked 2 and 3 in village C chose not to cooperate in a final effort to be the highest ranked farmer. With the game ending immediately after a player defects from the strategy they avoid retaliation and earn a higher profit.

Figure 20. Annual village balance: LU – Game 2
Figure 21. Picture of the change in players approach to cooperation

Players switched from communicating and play individually (top) to developing a village strategy (bottom).
3.4.2.3 Game Framework 3

In the third installment of Irrigania the goal was switched to maximizing village profit rather than the individuals’ profit. The overall accumulated profit for game 3 was $6550 ($437/yr), an increase of 12% and 18% compared to game 1 and 2, respectively. After discussing the results of game 2 and realizing that higher profits could be achieved through cooperation and strategy, all students decided to cooperate in game 3 to earn the highest village profit. The only difficulty for students was deciding on a unified strategy. Due to the differences in players’ experiences and outcomes through the first two games, players had different ideas for a “successful” strategy. Villages A and C negotiated a strategy, while village B chose to follow the guidance of the student who ranked first in game 1 and 2. This “expert” farmer’s credibility resulted in his irrigation strategy to be adopted for village B without the negotiation process that village A and C experienced. Each village adapted their strategy as the game went on and unlike UCFG, students in LU did not use a uniform irrigation scheme (same scheme for each player). Although, cooperation was maintained at 100% throughout the entirety of the game for village C, their final profit was considerably lower than the other two villages. Figure 22 shows the accumulated average profit for each village. The reason for the substantial difference was that although village C was working together, they decided to use groundwater for 80% of irrigation in year 1 and 2. The groundwater depth quickly dropped to 18 ft by year 2, resulting in its cost equal to $120 for an overall "profit" of -$20 (costing money per field), see Figure 23. Reviewing students' reflection papers revealed that game 3 was more enjoyable than game 1 and 2 because students could work together with their classmates under less stressful conditions, principally caused by competition and uncertainty. Also, although Tukey's method shows that game 3 is within both group A and B (therefore not statistically different from any other game) the mean of game 3 and
game 5 (the only game solely within group A) is $437 and $438. A larger standard deviation of results in game 3 caused it to narrowly miss exclusion from group B.

Figure 22. Accumulated village profits: LU – Game 3

Figure 23. Groundwater depth village comparison: LU – Game 3
3.4.2.4 Game Framework 4

The fourth game was again non-cooperative with the addition of unknown game length and random precipitation. The average profit in game 4 dropped to $363/yr as students depleted groundwater early in the game, relying on it for 67% and 40% of irrigation in the first two years, respectively. The annual balance for each village is shown in Figure 24. Adding random precipitation, unknown game length and in-game information disclosure did not notably affect the outcome of game 4 compared to game 1, the previous non-cooperative game. Performing an ANOVA test with grouping by Tukey’s we can conclude (p=0.308) that there is not sufficient evidence to reject the null hypothesis that $\mu_{ucfg}=\mu_{lu}$. The change in irrigation scheme between game 1 and 4 experienced mixed results, overall the change in irrigation type varied between ±20% as shown in Figure 25. The most obvious change was in year 1; groundwater increased 20% and riverwater decreased 20% in game 4, but overall there was no continuous change in irrigation use, either increase or decrease, for any of the water sources.

![Game 4: Yearly Balance](image)

Figure 24. Annual village balance: LU – Game 4
The only change to take place from game 4 was that students were now allowed to communicate with each other. Players were allowed to communicate in game 2 as well, but only 22% of players decided to use this option. However, in game 4 the proportion of cooperation increased to 84% and the average accumulated balance increased 13% from game 2 to $438/yr. Annual village profits are shown in Figure 26. Village A and B cooperated for the entirety of the game and village C began to cooperate at year 6 and continued until the end of the game. In this game, the partially cooperating village C outperformed the full cooperating villages A and B. One of the factors causing this to occur was because of random precipitation; the average precipitation for village A and B was exactly equal to 1, while village C experienced more precipitation, $P=1.46$, and as a result higher profits.
Figure 26. Annual village balance: LU – Game 5

Figure 27. Change in irrigation use in LU: Game 6 versus Game 4
3.4.2.6 Game Framework 6

For the final game of Irrigania with LU the game once again switched to non-cooperative, most similarly to game 4 except without information disclosure. In the first two rounds of play the average use of groundwater was 65% and 59%, while rainfed irrigation accounted for only 9% and 10%, respectively. Groundwater depth quickly dropped along with the overall profit of each village; the overall accumulated balance was $396/yr. Figure 28 shows the annual village balance of each village over the 15 years of the game.

![Game 6: Yearly Balance](image)

Figure 28. Annual village balance: LU – Game 6

3.4.3 Undergraduate UCF

For each game, the annual village profit, annual irrigation scheme, ANOVA results and accompanying information is either given in the following section or provided in APPENDIX D: UCF UNDERGRADUATE. Additionally, Table 5 provides an overview of information for comparing UCFU, LU and UCFG.
3.4.3.1 Game Framework 1

The average profit for the UCF undergraduate group was $5358 ($357/yr), but the two lab groups finished quite differently; the students in the first lab session averaged $6110 ($407/yr), while those in the second averaged $4605 ($307/yr). The primary reason for this was because lab group 2 depleted groundwater faster than lab group 1 and were therefore without profitable groundwater for most of the game. Figure 29 shows the difference between the groundwater depth and riverwater efficiency value (k), indicators of the profitability of these two irrigation sources. It can be seen that groundwater in lab group 2 drops quicker than lab group 1 and remains unprofitable for the remainder of the game. Additionally, as lab group 2 depleted groundwater they began to use riverwater more, resulting in lower river water efficiency (k). The accumulated annual profits of both lab sections are shown in Figure 30.

One of the main difficulties of playing Irrigania with the UCF undergraduate group was the time limitation associated with introducing the game and playing it during one sitting. From the responses of students, many felt that it took them the entirety of the first game to understand how to mix irrigation resources to earn high profit. Out of the 36 students in both lab sections, only one used a calculator to determine how different inputs to the groundwater cost and riverwater efficiency equations affected profit. The rest of the students experimented with different combinations of irrigation sources relying on a heuristic understanding of irrigation schemes to find an acceptable strategy. This may explain the extreme results occurring in game 1; this group contained both the maximum ($10,113 or $674/yr) and minimum ($1976 or $132/yr) profit of the three groups of students. Without disclosing each students' profit throughout game 1, no reference of a "good" or "bad" profit is established and players do not
necessarily know whether to adjust or not. Whether it was from their own experience experimenting with different irrigation schemes or from discussions with players in their village after game 1, students determined that groundwater is most profitable at the beginning of the game.

Figure 29. Groundwater depth and riverwater efficiency (k): UCFU – Game 1
Figure 30. Accumulated village profits: UCFU – Game 1

3.4.3.2 Game Framework 2

Allowing students to communicate in game 2 did not significantly increase players' accumulated profit; the average profit increased from 5358 ($357/yr) in game 1 to 5748 ($383/yr) in game 2. The accumulated village profit for this game is shown in Figure 31. Overall, the level of cooperation for the two lab sections was 60%, however students definitions of cooperation varied, some significantly more lax than either of the graduate classes. Much like game 2 for LU, UCFU had only 60% cooperation. For villages that did not cooperate, most students explained that their village either decided not to cooperate or could not come to a consensus on a strategy. The prevailing mindset for these players was that they could not trust the farmers in their village because they were competing for the same resources. Unlike players that cooperated in UCFG and LU which developed hard rules for cooperating (precise number of fields per water source per farmer), UCFU relied on quota-based management (e.g. players cannot exceed 5 fields irrigated with groundwater per round). Within villages utilizing quota-based management, many
players admitted to "bending the rules" as the game progressed. Another reason that some players chose to work individually was because of their success in the first game. Their decision not to cooperate in the second game was from the belief that their strategy from the previous game was good and if it was kept secret, they could again earn high profit.

Figure 31. Accumulated village profits: UCFU – Game 2

3.4.3.3 Game Framework 3

The final game played by the UCFU and provided in-game information disclosure regarding players' irrigation scheme and changed the goal from individual profit to village profit. As a result, cooperation increased from 60% in game 2 to 89% in game 3 and accumulated average profit increased to $6511 ($434/yr). Although the number of students cooperating with their village increased, it was the only of the three groups to be less than 100% cooperation under the framework of game 3. For the first time under this framework, full cooperation was not achieved (89%). One of the eight villages chose to work independently, but they were unsuccessful, earning a final ranking of 33, 34, 35 and 36 out of 36 players. This same group did not cooperate
in game 2 either and finished with a similarly low ranking. The reason players in this village did not cooperate was simply because they would not compromise on their preferred strategy and would rather play non-cooperatively. Although UCFU ($434/yr) did not earn as high of a profit as UCFG ($488/yr), their profit was similar to LU ($437/yr) which also relied primarily on heuristic learning for choosing irrigation schemes.

Figure 32. Accumulated profit of games – UCFU
### Table 5. Irrigania UCFU, LU and UCFG information

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#### 3.4.4 Inter-Group Comparison

To compare how participants performed under each of the institutional frameworks, ANOVA and Tukey's method were used. For the analysis, the response variable was average annual balance and the treatment groups were games, results are shown in Table 6. For UCFG, participants achieved the highest average annual balance in game 3: Community Rationality with Constant Variables. The next grouping (group B) contains game frameworks were 2, 4, 5 and 6 and the lowest scoring group (group C) contained game 1 and 4. Game 4 is contained in both group B and C, meaning that the average annual balance of game 4 is not significantly different.
than either group. For LU there was less statistical difference between games; games 1, 2, 3, and 6 were in both group A and B, while game 5 was solely in group A and game 4 in Group B. For the final group, UCF undergraduate, results of games 2 and 3 (group A) were significantly higher than game 1 (group B).

Table 6. Inter-group comparison of games using Tukey's method

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* Game 4 is not significantly different, therefore categorized as both group B and C

3.4.5 Group Comparison

While Table 6 shows the overall results of ANOVA methods with Tukey's method for determining whether the settings of each game (treatment groups) affected players profit or not, the complete analysis can be found in APPENDIX B: UCF GRADUATE, APPENDIX C: LUND UNIVERSITY GRADUATE, and APPENDIX D: UCF UNDERGRADUATE for UCFG, LU and UCFU, respectively. In addition to comparing within each of the three groups, a comparison between the groups is also important for understanding how the differences in implementation and the participants themselves affect the outcome. The average annual balance (response) was used to compare the differences between the three groups of participants (treatment group). Unlike Table 6, Table 7 is read horizontally, e.g., in game 1 the average
annual balance of UCFG and LU were similar, while UCFU was significantly lower at an overall error rate of $\alpha = 0.05$. Tukey's method shows that the balance for UCFG and LU were not statistically different from each other under the different frameworks of the games. For games 1, 2 and 3 UCFU averaged less than UCFG for all games and less than LU for game 1 and equal to LU for games 2 and 3.

The results of Tukey's method for comparing the difference in profit for the three groups of participants show that UCFG and LU students earned similar scores. The UCFUs scored significantly lower than their graduate counterpart, but similarly to those at LU in two of three games. The reasons for these differences can be explained by a couple main factors. The amount of time spent using Irrigania varied for each of the three groups of students, UCFG had the most time (played throughout the semester), followed by LU (3 sessions - 2 hours each) and finally UCFU (1 sessions - 1.5 hours). Students with UCFU had less time to understand the connection between irrigation sources and their use. With only 90 minutes they were also limited to three of the six games that groups 1 and 2 participated in. Although students were able to recognize and understand the main concepts of the game, CPR management and tragedy of the commons prevention, there was not adequate time for a complete debriefing period as done in the other groups. Additionally, some students were tentative to participate in group discussion during games with communication or in the short discussion period. In UCFG and 2, Irrigania and social media worked as a socializing agent by promoting discussion in and out of class, but with only one session for UCFU many students were content with as little discussion as possible.
Table 7. Group comparison of game using Tukey’s method

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3.4.6 Effects of Institutional Frameworks on CPRs

In game 1 most students are becoming familiar, primarily through trial and error, with the effects that different irrigation sources have on profit and what irrigation scheme will maximize their profit. Very few students try to preserve the resources, realizing that it would only provide a free-ride to other players. As one student wrote in her reflection paper, "The way they (players in her village) are playing, the groundwater level will decrease anyways, so why shall I not use it then?" This common sentiment led to a tragedy of the commons scenario during game 1. The behaviors manifested from this framework can be described as a combination of ignorant myopic and smart myopic management institutions (Madani & Dinar, 2012). Without prior knowledge of how the system functions, most students disregard the externalities derived of other farmers (ignorant) and focus on maximizing profit for the current year (myopic). However, as profits decline, players begin to recognize the interdependence between farmers and water resources and adapt their strategies to account for externalities (smart). Even accounting for externalities, however, players were seldom able to optimize profit without community rationality rules.
Overall, the game that cultivated the most profitable and sustainable use of resources was game 3: Community Rationality. UCFG and UCFU were most successful under the framework of game 3 and for LU it was approximately tied for the highest profit ($1 below their most profitable game). The settings of game 1 changed the objective from individual profit to village profit, eliminating the temptation of beneficiaries to free-ride and fostering the highest level of cooperation than any other framework, 100%, 100% and 89% for UCFG, LU and UCFU, respectively. The style of settings that promoted the second highest results were institutional frameworks 2, 5 and 6. For games 2 and 5 participants were allowed to communicate, but not required to cooperate, as a result there was partial-cooperation. Students in villages that wanted to cooperate often found it more challenging than they had originally thought it would be to reach an agreement. In game 2, students found that the most significant barrier to cooperation was trust in the player in ones villagers to follow agreed upon rules or strategies, the option to free-ride was very tempting. Information disclosure was not provided online in game 2, however players were still able to monitor to some extent by players’ yearly balance. Participants in LU found that allowing each other to view their laptops was an important aspect that encouraged trust and cooperation. By game 5, students understood the consequence of over abstraction and the benefits of long-term planning. In addition to cooperation and trust being important for achieving high scores, the credibility of participants also became a factor in establishing long-term irrigation strategies. If a player was labeled a "cheater" by his village in the discussion period, that reputation would often transfer to future games and cause players to be wary of trusting him. Students also achieved similar outcomes in game 6, which did not allow communication or information disclosure. Although communication was allowed in game 5, the temptation and inability to prevent players from free-riding limited the capability of managing
groundwater sustainably. The institutional framework that led to the worst economic performance by participants was game 1 and 4, which did not allow communication. Although some participants tried to conserve resources themselves, it was unsuccessful as competing players would free-ride and use high quantities of the more profitable resources until they were depleted. Overall, the factors determined to promote sustainable resource use were (1) communication (2) cooperation (3) trust (4) information disclosure (5) social learning (6) community mindset, and (7) long-term planning.
CHAPTER 4. CONCLUSION

The purpose of this study was to investigate the use of virtual environments within serious games as a platform for collecting information on diverse behavioral characteristics of from real-agents, which could be incorporated into distributed ABM. A review of serious games for environmental management was conducted to assess its current state. Irrigania, a web-based water sharing simulation game was chosen as a tool to analyze the behavior of real agents under different common pool resource management institutions. A secondary objective was to determine the effectiveness of Irrigania for teaching complex CPR management concepts including tragedy of the commons, externalities of the CPR systems, interdisciplinary nature of CPRs, sustainability, and the effects of human behavior and also for developing intangible skills such as critical-thinking, creative problem-solving, teamwork, etc.

The first research question relates to the potential of using online virtual environments to collect data for modeling agents’ behavior in water sharing problems. Because of the similarities found between beneficiaries behavior in both virtual and real CPR environments, virtual environments in serious games show potential as a source of information for behavioral characteristics for use in distributed agent-based models. Role-playing games have begun to be used for collecting information about stakeholders which is then used to develop ABMs (Janssen & Ostrom, 2006), particularly for modeling land-use change (D'Aquino, Le Page, Bousquet, & Bah, 2003; Mathevet, et al., 2007; Dray, et al., 2006). Online gaming shows similar promise for this application and is suggested as a reliable platform for information collection.

Research question 2 and 3 asked what effects on behavior and decision making do institutions and policies have on sustainable resource use in a virtual CPR environment and how
similar are the effects to real systems? The results of playing Irrigania demonstrate that different institutions and policies associated with CPR management have a significant effect on participants’ decisions making in the game. Some participants responded to non-cooperative settings in Irrigania’s virtual common which resulted in tragedy of the commons), but others were less tragic and correspond well with management institutions such as those suggested by Madani and Dinar (2012) (e.g. ignorant myopic, smart myopic, etc.). Students were able to learn about the effects of business-as-usual decision making in non-cooperative games, especially the self-seeking behavior of beneficiaries that leads to unsustainable practices (e.g. free-riding). In games that allowed communication the results varied, but were dependent upon many of the same factors recognized in literature. Overall, the factors determined to promote sustainable resource use were (1) communication (2) cooperation (3) trust (4) credibility (5) information disclosure and (6) social learning.

The last research question was related to what learning outcomes and skill acquisition can be acquired by participants through the use of the online SG Irrigania. Game-based learning using Irrigania was found to be a successful method for users to experience the externalities associated with CPR systems, the benefits of long-term planning to prevent tragedy of the commons, and the behavioral characteristics of beneficiaries within a CPR system. The most fundamental lesson was the cause and effect of over abstraction of CPRs and the factors that contribute to common dilemmas. Although students may have already been taught about these concepts, they felt that experiencing the role of a beneficiary in the system demonstrated factors including human behavior, externalities, and uncertainty that they had not realized played a prominent role in managing CPRs. Students were able to experience the difficulties imposed by
systems with no means of communication, in addition to those without beneficiaries willing to cooperate. Even in a system that is meant to benefit all participants (game 3: Community Rationality with Constant Variables), players had different opinions and ideas, which required communication, teamwork and negotiation to find a resolution. Overall, players learn that CPR management is not a zero-sum game, but that mutually beneficial solutions exist for both the individual and community. The key to implementing strategies is not necessarily technical in nature either, numerous variables (e.g. economic, social, etc.) influence the outcome of a conflict.

In addition to learning outcomes related to CPR management, Irrigania also supported the development of important skills for successful engineers. Soft skills including critical thinking, creative problem solving and teamwork were all present during gameplay and through the development of water management strategies. Students’ communication and negotiation skills were also important aspects of the game. Players often had different experiences from the games they were involved in than those in their current village, when it came to cooperative or partially cooperative games those that could express their ideas and negotiate a resolution often performed better than those that could not. UCFG students were also required to work together and schedule a time for all players to meet assemble online to complete the required number of rounds of Irrigania. At the beginning of its use, students were unorganized and often spent excess time waiting for everyone to get online. Time management improved over time as students began to plan the time of play further in advance, develop an initial strategy before the game began, and by sending online reminders to participants.
4.1 Recommendations and Limitations

The final objective of this study is to suggest recommendations based on the outcomes of the study. The first area of interest is using data collected from real-agents in SGs to validate the design of ABMs for water sharing problems. Online games has been suggested as a reliable platform for information collection, but improvements can be made to the process. Although the virtual environment in Irrigania was found to coincide with the behaviors and outcomes associated CPRs, there are limitations due to the games simplicity. Irrigania does not explicitly take into account factors such as environmental degradation or uniqueness of location and is not based on a physical model of hydrological processes. Improving the simulation to account for such factors could improve the authenticity of the results and therefore the behavior and decisions of the players. Introducing a storyline or narrative to Irrigania could also be beneficial, as research has shown that stakeholders using similar role-playing games generally accept games as an accurate representation of reality (Daré & Barreteau, 2003), which aligns with the flow experience (Csikszentmihalyi, 1991; Chen, 2007).

The second policy suggestion is based on the success of using Irrigania and other games like it (Dray, et al., 2006; D'Aquino, Le Page, Bousquet, & Bah, 2003; Lankford, Sokile, Yawson, & Lévite, The river basin game: A water dialogue tool, 2004) for promoting negotiation and discussion between parties. The success of these games lends credence not only to companion modeling (Bousquet, Trebuil, & Hardy, 2005), but to strategies such as shared vision planning for water management, which incorporates traditional water resource planning with structured public participation and collaborative computer modeling. Although models may not be a perfect representation of the problem, the process-based approach of creating the model
establishes communication between parties and generates new knowledge about the system, its components and interactions between them (Bagheri & Hjorth, 2006).

As stated earlier, serious games have already been shown to improve learning outcomes and skill development in many academic areas, but are not widely used in environmental management courses. However, there is a growing call for complementing traditional lecture driven courses with student-centered learning to improve students’ understanding of complex and dynamic systems (Hoekstra, 2012; Beavis & Beckmann, 2012; Barbalios, Ioannidou, Tzionas, & Paraskeuopoulos, 2013; Thompson, Ngambeki, Troch, Sivapalan, & Evangelou, 2012). This study shows that online serious games can be successful in meeting these needs and can be implemented in various ways (after school, in class and in lab), but improvements must be made. Drawbacks that face SGs for environmental management are due to limited availability, difficulty in implementation and deficiency of evaluations. Developing online SGs may overcome the first two of these obstacles, but there still needs to be a concerted effort by game developers to evaluate SGs.

A limitation of the review of environmental management serious games stems from the fact that there are many games that are not published in academic journals or even available online. The majority of serious games in environmental management disciplines have been created by enthusiastic academics for their own use as teaching tools and are not necessarily made publically available. As noted earlier, an online database of some sort for sharing serious games could be beneficial on multiple fronts: opportunities for collaborative projects, players' feedback, dissemination of SG news, etc.
APPENDIX A: PLAYER HANDBOUTS
What is Irrigania?
Irrigania is a web-based game about water conflict. In the game, you are a farmer within a village, dependent on limited water resources to irrigate your 10 fields. Available to you are three water sources: rainwater (RF), river water (RW), and groundwater (GW), each of which has an associated cost and revenue per field. The cost of rainwater and river water are set at $5 and $20 per field, respectively. However, the revenue from these two methods vary according to the amount of precipitation (normal, dry, or wet), for rainwater, and the amount of precipitation and use by competing farmers within your village, for river water. Groundwater, on the other hand, has a set revenue equal to $100 per field, but a varying cost that is dependent on the groundwater depth. Table 1 shows all costs and revenues per field for the different water supply options. Table 2 explains the variables found in Table 1.

Table 1. Costs and revenues for fields with different water supply. For variable explanations, see Table 2.

<table>
<thead>
<tr>
<th>Type of water supply for field</th>
<th>Cost per field</th>
<th>Revenue per field</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfed</td>
<td>5</td>
<td>30 (in normal year) 10 (in dry year) 40 (in wet year)</td>
</tr>
<tr>
<td>Irrigation with river water</td>
<td>20</td>
<td>100 k with k = min [1, 1 - ( \frac{F_{max}/n}{1.5+P} )]</td>
</tr>
<tr>
<td>Irrigation with groundwater</td>
<td>( g &lt; 8 : 20 ) ( g \geq 8 : 20 + (g-8)^2 )</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 2. Explanation of variables.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>( F_{river} )</td>
<td>Number of fields with river water irrigation</td>
</tr>
<tr>
<td>( F_{gw} )</td>
<td>Number of fields with groundwater irrigation</td>
</tr>
<tr>
<td>( g )</td>
<td>Depth to groundwater</td>
</tr>
<tr>
<td>( n )</td>
<td>Number of farmers in a village</td>
</tr>
<tr>
<td>( P )</td>
<td>Precipitation indicator (normal year: 1; dry year: 0; wet year: 2)</td>
</tr>
</tbody>
</table>

Objective?
To win the game of Irrigania, you must not only earn more money than the farmers in both your village, but also more than farmers in neighboring villages. To accomplish this, you will need to use an irrigation technique that maximizes profit, while conserving resources enough to keep cost down and revenue high. Your grade is determined by your rank (profit) in the class.

Rules?
1) No communication constraints
2) Precipitation = Random each year (P=0, 1, or 2)
3) Number of years (rounds) = Unknown
4) Villager's strategies shown after each year
**Steps to Playing Irrigania**

1) Go to: irrigania.ch
   - click on the student option
   - click ok (pressing enter does not work)

2) Enter information
   - Teacher Name: Kaveh
   - Village Cluster and Village name are below (page 3)
   - Farmer Name: Your first name
   - click log in

3) Game Play Information
   - The year for which you are selecting an irrigation scheme is at the top of the page
   - You are irrigating 10 fields, therefore, GW, RW, and RF must sum to 10 (the rainfed box computes itself based on GW and RW)
   - Economical status shows balance this year (which is actually the previous year's profit) and accumulated profit
   - Current hydrological conditions (CHC) shows depth to GW (g in the equation) and the previous year's cost of GW irrigation per field
   - GW depth begins at 5.0
   - The third line of CHC indicates the precipitation state (P)
   - The fourth/fifth line of CHC indicates the variable k from the previous year as a percent
   - Once you choose an irrigation scenario for the current year, click submit
   - You will select the following year's irrigation scheme according to the schedule (page 4). You will complete All years on the specified date.
   - Choose a time that all players in your village can be online, as you need all farmers to be online to submit your irrigation scheme
   - Your ranking within your village will be uploaded to Facebook at the end of the day.
Irrigania Village Cluster and Village Name

- Village Cluster: Radio
  - Village: Neon
    - Ahmed
    - Mahboubeh
    - Soroush
    - Mike
    - Michael Toth

- Village Cluster: Micro
  - Village: Helium
    - Hai
    - Steven
    - Stephanie
    - Seoyoung
    - Matthew

- Village Cluster: Infrared
  - Village: Argon
    - Andrew
    - Sultan
    - Michael Taaffe
    - Saeed
    - Daniel

- Village Cluster: Visible
  - Village: Krypton
    - Joseph
    - Kondwani
    - Jonathan
    - David

- Village Cluster: Ultraviolet
  - Village: Xenon
    - Jaclyn
    - Debapi
    - Kunal
    - Mousa

- Village Cluster: Gamma
  - Village: Radon
    - Milad
    - Jennifer
    - Tyler
    - Faraz
Schedule

*All submissions must be complete prior to 10:00 PM on each day

Thursday, 03/28/13

- All years

Figure 33. Irrigania procedures document
Irrigania 5

Village Cluster:
Village:
Farmer:

What is your initial strategy?

Did you change/adapt your strategy?

What did you learn from this game?

<table>
<thead>
<tr>
<th>Year</th>
<th>Ground Water</th>
<th>River Water</th>
<th>Rainfed Agriculture</th>
<th>Cooperative / Noncooperative</th>
<th>Balance</th>
<th>Accumulated Balance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year 1</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 2</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 3</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 4</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 5</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 6</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 7</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 8</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 9</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 10</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 11</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 12</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 13</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 14</td>
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<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 15</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 16</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 17</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Year 18</td>
<td></td>
<td></td>
<td></td>
<td>C / N</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(please scroll down in excel spreadsheet)

Figure 34. Example of player datasheet
APPENDIX B: UCF GRADUATE
Figure 35. Accumulated profit: UCFG – Games 1-3
Figure 36. Overall irrigation scheme: UCFG – Games 1-6
One-way ANOVA: Accumulated Average Profit versus Game

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
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<tbody>
<tr>
<td>Game</td>
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<td>242887</td>
<td>48577</td>
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<tr>
<td>Error</td>
<td>153</td>
<td>567455</td>
<td>3709</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>158</td>
<td>810342</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 60.90  R-Sq = 29.97%  R-Sq(adj) = 27.68%

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>95% Confidence Interval</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>365.18</td>
<td>67.05</td>
<td>(----*----)</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>415.23</td>
<td>61.72</td>
<td>(-----*----)</td>
</tr>
<tr>
<td>3</td>
<td>28</td>
<td>487.80</td>
<td>20.70</td>
<td>(-----*----)</td>
</tr>
<tr>
<td>4</td>
<td>26</td>
<td>377.21</td>
<td>86.39</td>
<td>(----*----)</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>417.36</td>
<td>57.00</td>
<td>(-----*----)</td>
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<tr>
<td>6</td>
<td>27</td>
<td>417.13</td>
<td>56.54</td>
<td>(-----*----)</td>
</tr>
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</table>

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Pooled StDev = 60.90

Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Game</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>28</td>
<td>487.80</td>
<td>A</td>
</tr>
<tr>
<td>5</td>
<td>27</td>
<td>417.36</td>
<td>B</td>
</tr>
<tr>
<td>6</td>
<td>27</td>
<td>417.13</td>
<td>B</td>
</tr>
<tr>
<td>2</td>
<td>28</td>
<td>415.23</td>
<td>B</td>
</tr>
<tr>
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<td>26</td>
<td>377.21</td>
<td>C</td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>365.18</td>
<td>C</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

All Pairwise Comparisons among Levels of Game

Individual confidence level = 99.55%

Game = 1 subtracted from:

<table>
<thead>
<tr>
<th>Game</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>99.5% Confidence Interval</th>
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<tbody>
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<td>2</td>
<td>0.61</td>
<td>50.05</td>
<td>99.50</td>
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<tr>
<td>3</td>
<td>73.18</td>
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<td>172.07</td>
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<td>4</td>
<td>-38.26</td>
<td>12.03</td>
<td>62.32</td>
<td>(-----*----)</td>
</tr>
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<td>5</td>
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<td>52.18</td>
<td>102.03</td>
<td>(-----*----)</td>
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<td>6</td>
<td>2.09</td>
<td>51.95</td>
<td>101.80</td>
<td>(-----*----)</td>
</tr>
</tbody>
</table>

---

-100   0   100   200
Figure 37. One-way ANOVA for UCFG: Accumulated average profit versus game
Figure 38. Residual plots for accumulated average profit: UCFG
APPENDIX C: LUND UNIVERSITY GRADUATE
Figure 39. Accumulated profit: LU – Games 1-3
Figure 40. Overall irrigation scheme: LU – Games 1-6
One-way ANOVA: Accumulated Average Balance versus Game

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
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<tr>
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<td>0.008</td>
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<td>54</td>
<td>151016</td>
<td>2797</td>
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</tr>
<tr>
<td>Total</td>
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<td>200511</td>
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</table>

S = 52.88  R-Sq = 24.68%  R-Sq(adj) = 17.71%

Individual 95% CIs For Mean Based on Pooled StDev

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<th>StDev</th>
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<th></th>
</tr>
</thead>
<tbody>
<tr>
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<td>388.40</td>
<td>55.18</td>
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</tr>
<tr>
<td>2</td>
<td>11</td>
<td>370.62</td>
<td>55.54</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>436.66</td>
<td>69.07</td>
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<td></td>
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<tr>
<td>4</td>
<td>9</td>
<td>363.45</td>
<td>49.86</td>
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Pooled StDev = 52.88

Grouping Information Using Tukey Method

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<th>Mean</th>
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<tbody>
<tr>
<td>5</td>
<td>10</td>
<td>437.99</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>9</td>
<td>436.66</td>
<td>A B</td>
</tr>
<tr>
<td>6</td>
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<td>388.40</td>
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<td>4</td>
<td>9</td>
<td>363.45</td>
<td>B</td>
</tr>
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</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals

All Pairwise Comparisons among Levels of Game

Individual confidence level = 99.54%

Game = 1 subtracted from:

<table>
<thead>
<tr>
<th>Game</th>
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<th>Upper</th>
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</table>
Figure 41. One-way ANOVA for LU: Accumulated average balance versus game
Figure 42. Residual plots for accumulated average balance: LU
Figure 43. Accumulated average balance: UCFU
Figure 44. Overall irrigation scheme: UCFU
One-way ANOVA: Average Annual Profit versus Game

<table>
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<tr>
<th>Source</th>
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</tr>
<tr>
<td>Total</td>
<td>107</td>
<td>805842</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 81.41   R-Sq = 13.65%   R-Sq(adj) = 12.01%

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>36</td>
<td>357.18</td>
<td>98.51</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>383.20</td>
<td>75.00</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>434.04</td>
<td>67.47</td>
</tr>
</tbody>
</table>

Pooled StDev = 81.41

Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Game</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>36</td>
<td>434.04</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>36</td>
<td>383.20</td>
<td>B</td>
</tr>
<tr>
<td>1</td>
<td>36</td>
<td>357.18</td>
<td>B</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Game

Individual confidence level = 98.07%

Game = 1 subtracted from:

<table>
<thead>
<tr>
<th>Game</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-19.56</td>
<td>26.02</td>
<td>71.61</td>
</tr>
<tr>
<td>3</td>
<td>31.27</td>
<td>76.86</td>
<td>122.45</td>
</tr>
</tbody>
</table>

Game = 2 subtracted from:

<table>
<thead>
<tr>
<th>Game</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>5.25</td>
<td>50.84</td>
<td>96.42</td>
</tr>
</tbody>
</table>

Figure 45. One-way ANOVA for UCFU: Average annual profit versus game
Figure 46. Residual plots for accumulated average balance: UCFU
APPENDIX E: GAME COMPARISON
Figure 47. Group comparison of accumulated average balance: Games 1-6
One-way ANOVA: Average Accumulated Balance versus Group

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>2</td>
<td>79495</td>
<td>39748</td>
<td>6.95</td>
<td>0.002</td>
</tr>
<tr>
<td>Error</td>
<td>67</td>
<td>383405</td>
<td>5722</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>69</td>
<td>462901</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

$S = 75.65$  $R$-Sq = 17.17%  $R$-Sq(adj) = 14.70%

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>23</td>
<td>365.18</td>
<td>67.05</td>
<td>-43.25</td>
<td>23.22</td>
<td>89.70</td>
</tr>
<tr>
<td>2</td>
<td>11</td>
<td>388.40</td>
<td>55.18</td>
<td>-106.59</td>
<td>-58.19</td>
<td>-9.78</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>306.99</td>
<td>85.20</td>
<td>-143.88</td>
<td>-81.41</td>
<td>-18.94</td>
</tr>
</tbody>
</table>

Pooled StDev = 75.65

Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>11</td>
<td>388.40</td>
<td>A</td>
</tr>
<tr>
<td>1</td>
<td>23</td>
<td>365.18</td>
<td>A</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>306.99</td>
<td>B</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Group

Individual confidence level = 98.07%

Group = 1 subtracted from:

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-43.25</td>
<td>23.22</td>
<td>89.70</td>
<td></td>
<td></td>
<td></td>
<td>-80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>-106.59</td>
<td>-58.19</td>
<td>-9.78</td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-80</td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td>160</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Group = 2 subtracted from:

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-143.88</td>
<td>-81.41</td>
<td>-18.94</td>
<td></td>
<td></td>
<td></td>
<td>-80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>-80</td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>0</td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>80</td>
<td></td>
<td>160</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 48. One-way ANOVA for game 1: Average accumulated balance versus group
Figure 49. Residual plots for average accumulated balance: Game 1
Game 2: One-way ANOVA: Average Accumulated Balance versus Group

Source    DF    SS     MS     F      P
Group      2   28349  14174  3.54  0.034
Error   72  288610   4008
Total   74  316958

S = 63.31   R-Sq = 8.94%   R-Sq(adj) = 6.41%

Individual 95% CIs For Mean Based on Pooled StDev
Level    N    Mean  StDev
---------    ------  ------
1        28  415.23  61.72
2        11  370.62  55.54
3        36  376.68  66.53

Means that do not share a letter are significantly different.

Grouping Information Using Tukey Method

Group    N    Mean  Grouping
1         28  415.23    A
3         36  376.68    B
2         11  370.62  A B

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Group

Individual confidence level = 98.05%

Group = 1 subtracted from:

Group    Lower  Center  Upper
---------    ------  ------  ------
2    -98.46  -44.62   9.23
3    -76.69  -38.56  -0.43

Group = 2 subtracted from:

Group    Lower  Center  Upper
---------    ------  ------  ------
3    -46.07   6.06  58.19

Figure 50. One-way ANOVA for game 2: Average accumulated balance versus group
Figure 51. Residual plots for average accumulated balance: Game 2
### Game 3: One-way ANOVA: Average Accumulated Balance versus Group

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>2</td>
<td>81467</td>
<td>40733</td>
<td>9.42</td>
<td>0.000</td>
</tr>
<tr>
<td>Error</td>
<td>70</td>
<td>302793</td>
<td>4326</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>72</td>
<td>384260</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\( S = 65.77 \) \quad \text{R-Sq} = 21.20\% \quad \text{R-Sq(adj)} = 18.95\%

#### Individual 95\% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>487.80</td>
<td>20.70</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>436.66</td>
<td>69.07</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>416.30</td>
<td>85.03</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

#### Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>28</td>
<td>487.80</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>436.66</td>
<td>A B</td>
</tr>
<tr>
<td>3</td>
<td>36</td>
<td>416.30</td>
<td>B</td>
</tr>
</tbody>
</table>

#### Tukey 95\% Simultaneous Confidence Intervals

**All Pairwise Comparisons among Levels of Group**

Individual confidence level = 98.08\%

**Group = 1 subtracted from:**

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-111.55</td>
<td>-51.14</td>
<td>9.27</td>
</tr>
<tr>
<td>3</td>
<td>-111.23</td>
<td>-71.50</td>
<td>-31.78</td>
</tr>
</tbody>
</table>

**Group = 2 subtracted from:**

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>-79.11</td>
<td>-20.36</td>
<td>38.40</td>
</tr>
</tbody>
</table>

---

**Figure 52.** One-way ANOVA for game 3: Average accumulated balance versus group
Figure 53. Residual plots for average accumulated balance: Game 3
## Game 4: One-way ANOVA: Average Accumulated Balance versus Group

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>1266</td>
<td>1266</td>
<td>0.20</td>
<td>0.656</td>
</tr>
<tr>
<td>Error</td>
<td>33</td>
<td>206469</td>
<td>6257</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>34</td>
<td>207735</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 79.10  R-Sq = 0.61%  R-Sq(adj) = 0.00%

### Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>377.21</td>
<td>86.39</td>
<td>(----------*----------)</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>363.45</td>
<td>49.86</td>
<td>(--------------------*--------------------)</td>
</tr>
</tbody>
</table>

Pooled StDev = 79.10

Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>26</td>
<td>377.21</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>9</td>
<td>363.45</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Group

Individual confidence level = 95.00%

Group = 1 subtracted from:

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
<th>CIs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-76.00</td>
<td>-13.76</td>
<td>48.48</td>
<td>(--------------------*--------------------)</td>
</tr>
</tbody>
</table>

Figure 54. One-way ANOVA for game 4: Average accumulated balance versus group
Figure 55. Residual plots for average accumulated balance: Game 4
Game 5: One-way ANOVA: Average Accumulated Balance versus Group

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>3106</td>
<td>3106</td>
<td>1.03</td>
<td>0.316</td>
</tr>
<tr>
<td>Error</td>
<td>35</td>
<td>105073</td>
<td>3002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>108178</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

\[ S = 54.79 \quad R-Sq = 2.87\% \quad \text{R-Sq(adj)} = 0.10\% \]

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
<th>--------</th>
<th>---------------</th>
</tr>
</thead>
</table>
| 1     | 27  | 417.36| 57.00 | (---------*--------)
| 2     | 10  | 437.99| 47.86 | (-----------------*
|       |     |       |       | )---------------|

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>10</td>
<td>437.99</td>
</tr>
<tr>
<td>1</td>
<td>27</td>
<td>417.36</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Group

<table>
<thead>
<tr>
<th>Individual confidence level = 95.00%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group = 1 subtracted from:</td>
</tr>
<tr>
<td>Group</td>
</tr>
</tbody>
</table>
| 2     | -20.55| 20.63  | 61.81 | (---------*--------)
|       | (-----+--------+--------+-----)
|       | -30   | 0      | 30    | 60  |

Figure 56. One-way ANOVA for game 5: Average accumulated balance versus group
Figure 57. Residual plots for average accumulated balance: Game 5
Game 6: One-way ANOVA: Average Accumulated Balance versus Group

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>SS</th>
<th>MS</th>
<th>F</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group</td>
<td>1</td>
<td>3351</td>
<td>3351</td>
<td>1.25</td>
<td>0.272</td>
</tr>
<tr>
<td>Error</td>
<td>35</td>
<td>94155</td>
<td>2690</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>36</td>
<td>97506</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S = 51.87  R-Sq = 3.44%  R-Sq(adj) = 0.68%

Individual 95% CIs For Mean Based on Pooled StDev

<table>
<thead>
<tr>
<th>Level</th>
<th>N</th>
<th>Mean</th>
<th>StDev</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>417.13</td>
<td>56.54</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>395.70</td>
<td>35.04</td>
</tr>
</tbody>
</table>

Pooled StDev = 51.87

Grouping Information Using Tukey Method

<table>
<thead>
<tr>
<th>Group</th>
<th>N</th>
<th>Mean</th>
<th>Grouping</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>27</td>
<td>417.13</td>
<td>A</td>
</tr>
<tr>
<td>2</td>
<td>10</td>
<td>395.70</td>
<td>A</td>
</tr>
</tbody>
</table>

Means that do not share a letter are significantly different.

Tukey 95% Simultaneous Confidence Intervals
All Pairwise Comparisons among Levels of Group

Individual confidence level = 95.00%

Group = 1 subtracted from:

<table>
<thead>
<tr>
<th>Group</th>
<th>Lower</th>
<th>Center</th>
<th>Upper</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>-60.41</td>
<td>-21.43</td>
<td>17.55</td>
</tr>
</tbody>
</table>

Figure 58. One-way ANOVA for game 6: Average accumulated balance versus group
Figure 59. Residual plots for average accumulated balance: Game 6
From:  UCF Institutional Review Board  
FWA0000351, IRB00001138

To:  Tyler Pierce

Date:  October 22, 2013

Study Title:  Virtual Interactions with Real-Agents for Sustainable Natural Resources Management

Dear Researcher,

As we discussed in e-mail correspondence over the past couple of weeks, the IRB cannot approve research after it has been conducted. Your use of data collected in your advisor’s classes may have been human subjects research. If so, it would have likely been determined to be in an Exempt category and participant consent may or may not have been required. As you have explained, the data did not include personal identifiers and so it is possible that the IRB determination would have been “not human subjects research.” The IRB, and not the researcher, is authorized to make this determination. In any event, the activities were minimal risk and there was no possibility of harm to the study participants.

I hope that this letter suits your needs. Please remember to consult with the IRB prior to conducting future research that involves human participants.

Sincerely,

Joanne Muratori, M.A., CIP  
IRB Coordinator
REFERENCES


DFC Intelligence. (2013). *Worldwide market forecasts for the video game and interactive entertainment industry*.


Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives that are restless... *EDUCAUSE Review, 41*(2), 1-16.


