EARTHQUAKE: GAME-BASED LEARNING FOR 21ST CENTURY STEM EDUCATION

A Dissertation

by

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ABSTRACT

To play is to learn. A lack of empirical research within game-based learning literature, however, has hindered educational stakeholders to make informed decisions about game-based learning for 21st century STEM education. In this study, I modified a research and development (R&D) process to create a collaborative-competitive educational board game illuminating elements of earthquake engineering. I oriented instruction- and game-design principles around 21st century science education to adapt the R&D process to develop the educational game, *Earthquake*. As part of the R&D, I evaluated *Earthquake* for empirical evidence to support the claim that game-play results in student gains in critical thinking, scientific argumentation, metacognitive abilities, and earthquake engineering content knowledge. I developed *Earthquake* with the aid of eight focus groups with varying levels of expertise in science education research, teaching, administration, and game-design. After developing a functional prototype, I pilot-tested *Earthquake* with teacher-participants (n=14) who engaged in semi-structured interviews after their game-play. I analyzed teacher interviews with constant comparison methodology. I used teachers' comments and feedback from content knowledge experts to integrate game modifications, implementing results to improve *Earthquake.* I added player roles, simplified phrasing on cards, and produced an introductory video. I then administered the modified *Earthquake* game to two groups of high school student-participants (n = 6), who played twice.

To seek evidence documenting support for my knowledge claim, I analyzed videotapes of students' game-play using a game-based learning checklist. My assessment of learning gains revealed increases in all categories of students' performance: critical thinking, metacognition, scientific argumentation, and earthquake engineering content knowledge acquisition. Players in both student-groups improved mostly in critical thinking, having doubled the number of exhibited instances of critical thinking between games. Players in the first group exhibited about a third more instances of metacognition between games, while players in the second group doubled such instances. Between games, players in both groups more than doubled the number of exhibited instances of using earthquake engineering content knowledge. The student-players expanded use of scientific argumentation for all game-based learning checklist categories. With empirical evidence, I conclude play and learning can connect for successful 21^{st} century STEM education.

DEDICATION

This dissertation is dedicated to Christine Reynolds Perkins.

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NOMENCLATURE

GBL	Game-based Learning
STEM	Science, Technology, Engineering, and Mathematics
R&D	Research and Development
NGSS	Next Generation Science Standards

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CHAPTER I

INTRODUCTION

Play is the highest form of research.

——*Albert Einstein*

In the history of human evolution, play has been thought of as a key factor in learning. In the 21st century classroom, instruction can be designed to resonate more naturally with students' learning and interests. Traditional instruction inadequately prepares many students for a fast-paced digitally-savvy 21st century world riddled with an unprecedented amount of knowledge. Core instructional components to 21st century science learning include having widespread significance across various science and engineering disciplines, affording tools for understanding complex systems-thinking, and connecting to life experiences and societal concerns that require scientific knowledge (*Next Generation Science Standards* [NGSS], 2013). What do these components look like in learning environments? How may 21st century goals empowering students to be learners and producers of knowledge (National Research Council [NRC], 2011) be integrated into learning environments? The serious answer may simply be to play. In and outside the classroom, successful 21st century science learning may look like the motivational and empowering act of playing (Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011; Squire, 2002).

Play is important because through it, we create (Sutton-Smith, 1995). Educational gaming induces 21st century learning (Edvardsen & Kulle, 2010) by nurturing creativity in participating learners (Dede, 2007). To help students think critically and metacognitively about urban and global challenges, the *Next Generation Science Standards* (NGSS, 2013) have established education benchmarks more relevant to 21st century learning. The *Next Generation Science Standards* (2013) support the position that all K-12 students should have access to a sound K-12 science education. Central to the entire discipline of science education is the concept of learning by doing–participating in one's own learning. Play is at the heart of participatory learning.

Play and learning are not separate disconnected affordances (Sutton-Smith, 1995). Effective game-based learning harnesses the benefit of play into an instructional medium. Traditionally, game-based learning has been undervalued by science educators, administrators, policy makers, teachers, and parents (Ecker, Müller, & Zylka, 2011). Opponents to game-based learning typically have subscribed to belief systems supportive of cookie-cutter schooling for an outdated industrial learning scheme. Proponents of game-based learning, however, typically have subscribed to scientifically-based thought systems. Contrasting with traditional education schemes, game-based learning may reorient instruction to prioritize experiential process for understanding over predetermined standardized endpoints (Dede, 2007); prioritizing conceptual understanding over fragmented content knowledge acquisition is a goal for 21st century science instruction (NGSS, 2013; NRC, 2011). Educational games have been fruitful as learning tools in past decades (Ellington, Gordon, & Fowlie, 1998) and hold promise for the future (Williamson & Sandford, 2011).

Problem Statement

What does 21st century science learning look like? Instruction harnessing students' interests, motivation, and experiences can support 21st century science learning by prioritizing practice over fragmented content breadth (Dede, 2007; NGSS, 2013). Beyond knowledge acquisition, successful 21st century science learning fosters "the development of an identity as a competent learner of science with motivation and interest to learn more" (NGSS, p. 286). If we value the U.S. maintaining a competitive edge in the global economy, we need to find and implement more instruction conducive to 21st century science learning (NRC, 2011). Gaming can be such a way for learners to understand ways the world works. Games afford players learning opportunities to practice the 21st century skills that are and will be found in the 21st century workplace (Dede; Prensky, 2001; Squire, 2002).

To date, there has been little agreement on what bounds the definition of an educational game or play (Salen & Zimmerman, 2004); scholars have used different definitions for the words play and game. Rarely are game- and instructional-design both included in creating educational games (Ecker, Müller, & Zylka, 2011). Further, the application of game-based learning has not been adequately realized in learning environments. This has been in part due to a lack of empirical evidence supporting beneficial claims (Bonanno, 2010; McClarty et al., 2012). With insufficient emphasis on the context of game-based learning (Federation of American Scientists, 2006), the field needs a game that has undergone a rigorous research and development (R&D) process from the beginning to the end. To launch game-based learning into a more accessible form of instruction, the field needs a game built from scratch that is aligned with 21st century learning and is backed with empirical evidence supportive of positive educative outcomes. Without research providing stakeholders empirically validated evidence of the profound benefits of educational gaming, we may continue to miss out on the real solutions play offers 21st century science instruction.

Significance

Recorded games have been used for learning in ancient Greece and Rome (Gutek, 1995) and have been used as instructional tools ever since for centuries (Cruickshank & Ross, 1980)–despite the belief that games for education have just recently been developed (Ellington, Gordon, & Fowlie, 1998). During the Great Depression and subsequent recovery, academic and school libraries facilitated educational games for teachers to use in classrooms (Nicholson, 2013). In the 1980's, the U.S. implemented game-based learning for military training (Frank, 2012). This government-realized success of play for learning, combined with technological advances in gaming systems, has resulted in unprecedented growth in gaming (Malaby, 2007). An entire subculture of gamers thrive. Why? To be human, to play, and to learn are inextricably and contextually linked (Huizinga, 1938/1980).

Most game-based learning studies have only focused on domain-specific game descriptions or non-empirical outcomes. The literature base primarily consists of internal evaluations; first-hand narratives of only a few R&D phases; works elaborating the benefits of different forms of game-based learning; and biased conjectures with no addressed epistemological, historical, or cognitive assumptions of what the researcher(s)' stance(s) on play are. Fortunately, several notable scientists have contributed in helping the state of game-based learning rise above distracting fragmentation. Kafai (2006) has concisely discussed constructivist gaming as a subset of game-based learning in which students themselves design games as a form of instruction. Forerunners have created games for students to play in an already established game-space, such as *Alien Rescue* (Pederson, 2003) and *Extinction: The Game of Ecology* (Hubbell & Piret, 1970). *Alien Rescue* is a problem-based computer game mapping a terrestrial environment in which students rescue alien life forms while learning astronomy and practicing science. *Extinction: The Game of Ecology* is based on Darwin's Theory of Evolution, and highlights principles of ecology associated with the survival of species. In playing well-constructed games such as the *Extinction* game, learners are provided opportunities to develop new and situated conceptualizations through participatory experiences in complex domains that would otherwise be unapproachable (Gee, 2003; Wideman et al., 2007).

Researchers have reported the need for a more instructionally relevant frame-of-mind in game-design (Edvardsen & Kulle, 2010; Kafai, 2006), for more empirical evidence (McClarty et al., 2012; Squire, 2002) on the effectiveness of games as learning environments (Federation of American Scientists, 2006; O'Neil, Wainess, & Baker, 2005), and to integrate learning theories into game design (Ecker, Müller, & Zylka, 2011). I have not found previous studies that have chronicled a systematic educational game R&D synthesizing instruction- and game-design.

The analysis of instruction in educational gaming is severely lacking (Schwartz & Bayliss, 2011; van Staalduinen, 2011), specifically with respect to social learning (Rossiter & Reeve, 2010). The commonly used pre- and post-test evaluation format (see van Staalduinen), though easily administered, inadequately captures how students interact with an educational game and fails to provide sufficient evidence about performance objectives (Schwartz & Bayliss, 2011)–a critical phase of any R&D process. Researchers have called for evaluation in the form of a case study to explore how students actually play to allow for emerging evidence of meaningful learning (Rossiter & Reeve). This research can be significant for educational game designers by providing the field with a case study centered on the R&D of an educational game with respect to both instruction- and game-design principles. I have been unable to find any such study in the literature–only calls for needed research (Bonanno, 2010; Rossiter & Reeve; Schwartz & Bayliss).

Statement of Purpose

Two primary aims of this study guided my work in this study. First, I desired to conduct a literature review on play and learning that includes research from various academic disciplines. Second, I desired to chronicle an R&D case study engaging learners in playing an education game. I examined methodological, conceptual, and theoretical issues about play and learning to review the literature, which illustrates a critical examination of previous research from diverse viewpoints. In the comprehensive literature review, I discussed play and learning by acknowledging philosophical, historical, epistemological, sociological, and cognitive perspectives of humanity's recorded relationships with play as an educational practice. In addition to laying the groundwork for a cohesive framework about play and learning, I used the literature review to set the stage for the second aim of the study.

Well-designed games provide opportunities to practice important 21st century skills (Prensky, 2001; Rossiter & Reeve, 2010; Squire, 2002), such as critical thinking, scientific argumentation, and metacognition (NRC, 2011, 2007, 2000). Well-constructed science educational games also blend science and engineering design (see Schwartz & Bayliss, 2011), which is an important new perspective adopted for the *Next Generation Science Standards* (NGSS, 2013). Accordingly, I develop a study to present the R&D of a game providing secondary school learners with opportunities to develop 21st century cognitive skills and to construct content knowledge about earthquake engineering. Aligned with NGSS standards for a scientifically literate citizenry, I created the game to provide learners with opportunities to do science, understand science, produce scientific knowledge and abilities, and blend science with engineering design. I chose the knowledge domain anchoring the game to be earthquake engineering, a perfect context due to the complexities, systems-thinking, collaborative discourse, and real-life relevancy the domain offers instruction.

In summary, I centered my knowledge claim on the idea that contextualizing learning authentically can enhance the learning environment, providing learners with autonomy and a community-sense of belonging (Rossiter & Reeve, 2010). Furthermore, I desired to address U.S. reform documents stating that K-12 science education fails to "provide students with engaging opportunities to experience how science is actually done" (NRC, 2011, p. 1). Along with a comprehensive literature review, I therefore conducted an authentic R&D study. Accordingly, I aimed to empirically validate outcomes of students' play as they engaged in a collaborative-competitive board game anchored in engineering design.

Research Questions

I proposed in this study neither to reconstruct nor to build upon conflictions about play and learning in an attempt to propose a unifying theory. Rather, I proposed to deconstruct our understanding of educational gaming to its core by exploring the essence of play as we know it. The guiding question for the literature review, therefore, remained general: What is play and how does it connect to learning?

I also addressed research questions specifically for the R&D of the created game. My main goal in conducting the R&D was to generate an instructionally sound educational game anchored around earthquake engineering. My guiding research questions for the second part of the dissertation were: (1) What major steps will I need to modify in a typical R&D process to develop a prototype for an educational game? (2) What major steps will I need to take to inform the original design of the game prototype and then pilot test the prototype? (3) What steps will I take to make modifications and revise the prototype of the game before testing it with high school learners? (4) What evidence from game-play exists that students have improved abilities in critical thinking, scientific argumentation, and metacognition, and understanding of earthquake engineering content knowledge? (5) What input from the final phase of the R&D process informs any further game revisions?

I chose a qualitative research strategy for the proposed case study that follows the instructional design template proposed by Dick, Carey, and Carey (2001), which consists of five phases: *Analyze, Develop, Design, Implement,* and *Evaluate*. Dick, Carey, and Carey have developed the R&D model as a general methodology for producing instruction, which has been used by both instructional novices and seasoned practitioners (Dick, Carey, & Carey, 2001). Iterative and nonlinear, the R&D model is an appropriate template for inductive projects (Dick, 1996).

The instructional design scheme structures the foundation for the study's R&D process. Following educational game design recommendations from Schwartz and Bayliss (2011), I chose to replace the word "learning" with "playing" in Dick, Carey, and Carey's instructional design scheme. I chose to follow a case study design to carry out the study. I first conducted a comprehensive review of literature spanning millennia and academic domains. By employing qualitative and empirical modes of R&D, I attempted to illuminate my method to synthesize instruction- and game-design. Within each of the five R&D phases (i.e., *Analyze, Develop, Design, Implement,* and *Evaluate*), I superimposed game-design principles onto the R&D instruction-design model.

To develop the first version of the game, I conducted a series of focus groups engaging game designers. The first version was then played by teachers in a professional development workshop setting. With these teachers' input and additional input from engineering content specialists, I then made revisions before administering the game with high school students, who played the game twice. The students and I met in one session lasting a total of four hours.

I drew research data in this dissertation from two main sources: audio-recorded, post-play teacher-group interviews, and video- recordings of students playing the subsequently modified version of the game. I transcribed and analyzed teacher-group interviews through constant comparative methods for naturalistic inquiry (Erlandson, Harris, Skipper, & Allen, 1993) with the goal of developing general categories that best captured the game's essence and indicated needs for modifications. Students then played a modification of the game twice. I transcribed video-recordings of student game-play. To analyze the student transcriptions, I created the *Game-based Learning (GBL) Checklist*. After an established inter-coder reliability, I used the *GBL Checklist* as an instrument to capture evidence of students' performance in the areas of interest: critical thinking, metacognition, scientific argumentation, and use of earthquake engineering content knowledge.

Limitations

No Shoulders of Giants Upon Which to Build

While researchers have called for a meticulous study for the authentic R&D of a collaborative educational game for 21st century learning (e.g., Rossiter & Reeve; Schwartz & Bayliss, 2011; van Staalduinen, 2011), little research exists to serve as guideposts for the evaluation of an educational game. Most terminology used in educational gaming has been inconsistent among domains, researchers, and even performance objectives. Furthermore, no cohesive and agreed upon set of units of measurement have been established with which to calibrate data, conduct analyses, formulate results, or evaluate learning success. A limitation of this dissertation, thus, is that I do not have a similar study with which to reference relevant research protocols or strategies.

A further limitation is that few researchers creating educational games have adopted an instructional or learning theory to guide their design. Many researchers have assumed that mere engagement was justifiable evidence of successful learning. My examination of the literature also revealed game- and instruction-design as relatively separate research domains (Bonanno, 2010; van Staalduinen, 2011); and within and between both fields, an accepted agreement on the definitions of *game* or *play* did not exist.

Finally, I found no studies explicitly detailing a full R&D process of educational gaming. Inconsistent terminology and misrepresentations pervaded the minimal research I read about game-based learning. Most researchers entangled their games with computer technology (Rossiter & Reeve, 2010); I found that few researchers have reported associations with a non-digitized educational game.

A Study with Small Numbers of Participants

I limited this study to the number (n=14) of teacher-participants available to play the game prototype. During a week-long professional development workshop on earthquake engineering, the teachers played in four groups for about an hour and a half. Afterwards, I separately interviewed the four teacher-groups following a semi-structured interview protocol. The interviews were limited to about 30 minutes. Furthermore, my evaluation of the subsequently revised game was limited to a convenience sample of six high school students who played the game twice in one sitting, with each game lasting about an hour and a half. As a result, I therefore restricted any attempts to generalize results beyond data from the audio-recorded teacher interviews and the video-recorded student game-play.

Methods of Data Collection

Another limitation resides in the method of data collection for student game-play. I originally relied on a discussion group planned at the end of playing time in the form of a semi-structured group interview. I intended this student-group interview to be a major source of data, as had been the case with the teacher-group interviews. However, the students were not as open as the teachers. Though the students were energetic and engaged during their two games, they appeared very reserved during the interview, which resulted in an insufficient amount of data. I was therefore limited to using only the video-recordings of student play to seek for evidence related to student outcomes.

For this *Evaluate* phase of the R&D process, I was unable to find an existing assessment instrument on educational gaming. As a result, I researched and developed the *GBL Checklist* to systematically capture and assess the students' video-recorded game-play. Even though I self-designed the checklist, I did implement a process to establish the validity and reliability of the *GBL Checklist*, which was specifically designed to document the outcomes of interest for the study. Therefore, I acknowledge that the *GBL Checklist* cannot be generalized beyond its application for this specific game, although the process by which it was developed would be generalizable to other researchers desiring to document specified outcomes associated with the play of another game.

Key Terms

A variety of definitions of the term *play* have been suggested. In this dissertation, I used conceptualizations proffered by Johan Huizinga. I derived a philosophically grounded framework generalizable enough for salient compatibility with classroom learning from Huizinga (see Schwartz & Bayliss, 2011). Huizinga outlined one of the first recorded play platforms (Huizinga, 1938/1980), that: entry into play is a voluntary act, unable to sustain suspension or deference; play transcends ordinary life into a mystic consciousness; play requires order, through which rules should not be broken lest one becomes a spoilsport; and that productive play is socially rooted. Huizinga has argued that play is not the opposite of seriousness, but the opposite of depression (1938/1980).

For this dissertation, I followed the definition of a *game* articulated by Csikszentmihalyi (1990) who has conceptualized that, “games fill out the interludes of the cultural script” (p. 81). Games offer players more freedom to learn from mistakes, errors, and failures (Gee, 2003; Veen & Staalduinen, 2009). A quasi-bounded and socially justified arena of arranged potentialities that produce interpretable outcomes (Malay, 2007), a game is a medium through which play can function. Game-based learning invites players to apply deeper levels of knowledge and skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956; Webb, 1997) while developing 21st century abilities (Galarneau & Zibit, 2011; Gee, 2009; Kirriemuir & McFarlane, 2004; Williamson & Sandford, 2011).

Structure of the Dissertation

The overall structure of the dissertation takes the traditional form of five chapters, including this introductory chapter. Chapters Two through Four appear in article format, as they represent the three articles to be published to report the results of research (see Table 1). In the form of a literature review as a stand-alone paper, I wrote

Table 1

Article Structure of the Dissertation

Article	R&D Focus	Data Source(s)	Methodology	Goal
1	Phase 1: Analysis	Scholarly journals, books, games, conferences	Comprehensive literature review	Explore foundations of play and learning
2	Phase 2-4: Develop, design, implement	Audio-recorded teacher interviews after having played the game once	Constant comparison of interview transcriptions	Develop game prototype, test prototype with teachers, implement modifications emergent from constant comparison
3	Phase 5: Evaluate	Video-recordings of students playing the game twice	Create and use *Game-based Learning Checklist* to assess student game-play per game and between-game gains	Capture empirical evidence of the game's educative efficacy

Chapter Two to lay out the philosophical, epistemological, and socio-cognitive foundations of play and learning. Within the framework of play and learning bounded for the context of game-based learning, the third and fourth chapters chronicle the full R&D of the game. The first four phases of the R&D (i.e., *Analyze, Develop, Design, and Implement)* process are the focus of Chapter Three, the data of which comes from teacher interviews. The fifth R&D phase, *Evaluate,* is the focus of Chapter Four. This fifth phase is a chapter all in itself. In Chapter Four, I respond to the huge gap in the literature regarding this phase and reflect on my evaluation of students' game-play, which was a meticulous and time-consuming process. Finally, the conclusive fifth chapter draws upon the entire dissertation, tying up the various theoretical and empirical strands in order to help meaningful game-based learning more accessible for researchers, schools, teachers, parents, students, and society at large.

CHAPTER II

LITERATURE REVIEW ON GAME-BASED LEARNING

The time has come to embrace educational play as a means to 21st century STEM education. Productive in learning environments, play supports student agency (Podolefsky, Rehn, & Perkins, 2013), that is, the ability to act out one's personal interests, goals, and willful being (Wright, 2012). As ideas about knowledge and learning change with the landscape of 21st century life (Starkey, 2011), educational games pick up where traditional 20th century instruction has left off. With powerful motivational qualities (Deen & Schouten, 2011; McClarty et al., 2012) and the inherent potential to capitalize on situated learning contexts (Ecker, Müller, & Zylka, 2011; Schwartz & Bayliss, 2011), educational games are gaining momentum as innovative instructional tools for 21st century learning (Podolefsky, Rehn, & Perkins; Prensky, 2001; Squire, 2002; Williamson & Sandford, 2011). Prompted by unprecedented growth in the computer game industry, game scholarship affords opportunities to contribute to culture at a scope surpassing prior aspirations (Malaby, 2007). Contrasting with traditional education schemes, game-based learning can reorient instruction to prioritize experiential process over predetermined standardized endpoints–a major science learning theme articulated in the *Next Generation Science Standards* (NGSS, 2013).

Educational games have been fruitful as learning tools in past decades (Deter, 2015; Ellington, Gordon, & Fowlie, 1998) and hold promise for the future (Ecker, Müller, & Zylka, 2011; Prensky, 2001; Squire, 2002). Educational gaming researchers have called for a more instructionally relevant frame-of-mind (Edvardsen & Kulle, 2010; Kafai, 2006), for more empirical evidence (McClarty et al., 2012; Squire) on the effectiveness of games as learning environments (Federation of American Scientists, 2006; O'Neil, Wainess, & Baker, 2005), and to integrate learning theories into game design (Ecker, Müller, & Zylka). However, the fundamental crux of gaming in educational research has too often left unaddressed conceptual and theoretical frameworks (Squire) proffering advanced conceptualizations. My goal in this literature review was not to reconstruct nor build upon conflictions in an attempt to propose a unifying theory, but to deconstruct understandings of educational gaming to the core by exploring the essence of play as we know it. What is play and how does it connect to learning?

Philosophical and Historical Foundations of Play

From Plato to Piaget, the notion of play has fluctuated through cultural and biological identifications as a patron to humanizing subjectivity (Singer, 1973; Sutton-Smith, 1995) and as an animalistic component to well-being (Fagen, 1981; Sutton-Smith). Piaget (1952) theorized play as a way for children to understand operations of the physical world, yet relegated play to a status devoid of intellectual functionality in and of itself; play merely filled cognitive gaps in which language would later occupy upon a child's progressed intellectual development (Sutton-Smith, 1966). To Piaget

(1966), play was basically an assimilation of fragments of reality to the self. In a conversely abstract regard, Plato (trans. 1997) viewed play as situated within a grand seriousness:

> What I assert is this; –that a man ought to be in serious earnest about serious things, and not about trifles; and that the object really worthy of all serious and blessed effort is God, while man is created, as we said above, to be a plaything of God, and the best part of him is surely just that; and thus I say that every man and woman ought to pass through life in accordance with this character, playing the noblest of pastimes, being otherwise minded than they now are. (p. 803)

Piaget sought to scaffold children's intellectual development through play. Plato called for peace in humanity through play. And, religious texts have drawn upon play for creation. The function of play has ranged from null fillers of time-space to the holiest of rituals (Huizinga, 1938/1980). A reading from the *Book of Wisdom* elucidated a play-element of humanity:

> The Lord possessed me in the beginning of His ways, before He made anything from the beginning. I was set up from eternity, and of old before the earth was made…I was with Him forming all things. And I was delighted every day, playing before Him at all times; playing in the world, and my delights were to be with children of men. (Epistle Proverbs 7:22-35, English Standard Version)

Wisdom played with humanity; and, we have played back.

A dispositional attitude characterized by readiness to improvise in the face of contingency (Malaby, 2007), play has been deeply enlightening and empowering (Schiller, 1794/1965; Sutton-Smith, 1995). The German philosopher historian Friedrich Schiller (1759-1805) saw play as a means of social empowerment for the disenfranchised peoples of the French Revolution, “For, to declare it once and for all, Man plays only when he is in the full sense of the word a man and he is only wholly Man when he is playing” (Schiller, p. 80). To Schiller, play encompassed all that was neither objectively nor subjectively conditional and was that which refrained from sustaining both inward and outward necessity.

Clearly, the diverse notion of play has been culturally and contextually situated (Rieber, 1996). There is no definitive agreed upon conceptualization of play by scholars (Salen & Zimmerman, 2004). The play theorist Brian Sutton-Smith organized play by function into four historically, culturally, and psychologically oriented categories: play as progress, power, fantasy, and of the self (1995). A philosophically grounded framework generalizable enough for salient compatibility with classroom learning has been derived from Huizinga (Schwartz & Bayliss, 2011) who outlined one of the first recorded play platforms (Huizinga, 1938/1980), that:

- Entry into play is a voluntary act, unable to sustain suspension or deference.
- Play transcends ordinary life into a mystic consciousness.
- Play requires order, through which rules should not be broken lest one becomes a spoilsport.
- Productive play is socially rooted.

The Dutch historian Johan Huizinga (1872-1945) pioneered the study of integrating the concept of play into that of culture (Anchor, 1978), philosophizing that play and seriousness are not opposing sides to a socially constructed axis, but spheres superimposed to varying degrees (Huizinga, 1938/1980). Huizinga viewed the opposite of play as neither work nor seriousness; rather, it has been viewed as depression (Sutton-Smith, 1997). Though work and play have been argued as not dichotomous (Stevens, 1980), as humans we, "can deny seriousness, but not play" (Huizinga, p.3), for play is the fountain of creativity. Humanity creates.

An integral part of culture, the balance between seriousness and play manifests in art, war, law, education, and more. Play and knowledge, for example, cultivate each other. The Hindi Brahmins, Toradja of Central Celebes, Ancient Greeks, and Vikings historically passed esoteric knowledge through the playing of riddle games (Huizinga, 1938/1980). The Ancient Greek philosopher Clearchus theorized that "the ancients…used it [riddle-solving] as proof of their education" (as cited in Huizinga, p. 115). The Ancient Greek philosophers Pindar and Theocritus composed algebraic word-problem riddles (Montfort, 2005). During the Renaissance, humanist clergyman wrote riddle books, utilized as instructional tools (Gutek, 1995), as a catechism for those elite children studying liturgy (Huizinga). Though we see games functioning in classrooms throughout the 20th century, the playing of games has served as instruction for centuries (Cruickshank & Ross, 1980), despite the belief that games for education has just recently developed (Ellington, Gordon, & Fowlie, 1998).

The Roman orators Cicero and Quintilian incorporated games into their schools, though not for educative means directly themselves but for recess to support boys' physical development aligned with the ideal Roman orator (Gutek, 1995). Such a predetermined Roman school play-factor hindered the act of playing to create something new–a theme Huizinga eluded as an influential factor in the fall of the Roman Empire. To Huizinga, an archaic unity of play and ritual was essential for cultural growth. Culture was *sub specie ludi*, which translates to *play precedes culture*; civilization arose and unfolded in and as play (Huizinga, 1938/1980).

A play theorist forerunner, Huizinga has been grossly misrepresented in literature spanning time and academic domains. Against his articulated will, English translations of his literary works and lecture titles often read "The Play Element in Culture" and not the correct "The Play Element of Culture," thus fundamentally misdirecting Huizinga's entire thesis that culture was *sub specie ludi* (Huizinga, 1938/1980). To grasp his seminal work *Homo Ludens*, entire chapters must be read in whole and reread. Otherwise, one may close the book mid-chapter under the inaccurate impression Huizinga has finished an argument. Huizinga's style of writing was ironically playful;

he played with notions as a means to build arguments. Huizinga set the stage for presenting stances by opening an argument with a point he eventually rebuts through philosophical logic.

Unfortunately, this may have confused researchers into thinking Huizinga has made a claim within his opening point, when he has made the opposite claim upon completion of a specific logic sequence. For example, in his critique of *Homo Ludens*, Robert Anchor (1978) cited that Huizinga had claimed "play is the opposite of seriousness, at least for the mature adult" (Anchor, p. 70). Anchor was most likely referring to Huizinga's critique of neo-platonic fashions in 17th century Europe reflective of a superficial play-factor. Huizinga (1938/1980) did write "…play is the direct opposite of seriousness" (p. 5). Huizinga, however, wrote that sentence to introduce the following paragraphs that refute the claim of play and seriousness as opposites. Huizinga had set the stage for an argument to be rebutted, a notion down his logic sequence Anchor had not addressed. Unfortunately, Anchor was not alone in having taken Huizinga's sentence out of context. Garris, Ahler, and Driskell (2002) in "Games, Motivation, and Learning: A Research and Practice Model" also claimed that Huizinga argued in *Homo Ludens* "that play is the direct opposite of seriousness" (Garris, Ahler, & Driskell, p. 459) –to which the introductory chapter of *Homo Ludens* clearly presented the contrary with "but let it be emphasized again that genuine and spontaneous play can be profoundly serious" (Huizinga, p. 20).

These misrepresentations have been particularly relevant for educational gaming, as gaming has been considered by many as less than, unproductive, and not serious (Ellington, Gordon, & Fowlie, 1998; Rieber, 1996; Squire, 2002) enough for something as sacred as our children's education or life-long learning. These pervading predispositions block students from experiencing the authentic, transformative, and empowering effects of educational games. Educational research on gaming often employs phrases and buzz words further solidifying contrasting notions of playing and seriousness, as if the two inherently oppose one another. The title of the article "Not Just Fun, but Serious Strategies: Using Meta-Cognitive Strategies in Game-Based Learning" (see Kim, Park, & Baek, 2009) brings attention to the underscored element of "fun" and the sometimes elevated notion of "serious" in play. The undertone was that for gaming to be taken as legitimate, it must be more than fun–to be valid in educational research, playing must be serious. To the contrary, Huizinga regarded fun as the essence of play (Garrison, Ahler, & Driskell, 2002; Huizinga, 1938/1980).

Much can be learned about our fragmented conceptualizations of play by studying titles of journal articles. The title to Nixon's 1998 article "Fun and Games are Serious Business" was more aligned with the play-factor of culture shared by Huizinga, Schiller, and Sutton-Smith. We must be cognizant of which words we use and why. With a history of misrepresentation (Huizinga, 1938/1980; Rieber, 1996) and abundant miscommunication, the words "fun," "serious," and "play," should be not be used frivolously for fashion's sake or as a political meme. Understanding the cultural significance and transformations of their various meanings may help us communicate with each other and with those outside the field of education. Though there has been an international call for empirical evidence on what elements of play work best for different goals and environments, perhaps a more pragmatic approach to elevate the status and effective function of educational gaming would be for researchers to directly and coherently address philosophical stances within studies.

What one researcher calls “serious play” may not be what another researcher calls “serious play.” The phrase “serious play” was first coined in 1917 by the German gestalt psychologist Köhler (Bruner, 1972) as a way of describing how young apes solved problems by observing others (Köhler, 1926, p. 157). Often found in educational gaming research, the phrase “serious play” is rarely accompanied with any reference– some researchers have gone as far to claim serious games do not even exist (see Haring, Chakinska, & Ritterfeld, 2011). In anthropology, Ortner (1999) proposed “serious games” (p. 23) as a category to illuminate how the distinction between work and leisure was a modernist construct, denoting “serious” as an adjective to “emphasize the constant play of power in the games of life, and the fact that, for most people most of the time, a great deal is at stake.” Regardless, failure is still a critical element of learning. When in a perceived life or death situation, is it not better to be safely bounded in a play-sphere (Gee, 2003; Veen & Staalduinen, 2009)?

To further complicate communications, a game has often been considered as a serious game in educational research if it affects the player with good intention beyond the means of entertainment (Ritterfeld, Cody, & Vorderer, 2009). For researchers adopting this stance, what then is the connection, if any, between play and fun as differentiated from entertainment and fun? Without sufficient explication and connection of historical, cultural, or social contexts, such phrases may unfortunately fuel the dichotomous misconception between play and seriousness. Just as physicists require units to be labeled on the axes of published graphs to convey variable relationships, our philosophical foundations and associated rationales must be made more visible in our work.

A pioneering researcher of educational gaming environments to whom we owe thanks for explicating important modern notions of play, Lloyd Rieber (1996) wrote, "An understanding of the philosophical assumptions of play is a critical first step to understanding its role or value in learning and instruction" (p. 45) but that "…considerable value is placed on practical instructional applications, rather than espousing one theoretical or philosophical position over another" (p. 55). Rieber aimed to discuss some of the best ideas from several philosophical stances, highlighting axiomatic notions that compartmentalized play into prescribed schemes, such as Piaget's (1952) play theory, Loy and Kenyon's (1981) four broad categories of game, and a checklist for Csikszentmihalyi's (1990) flow theory–the balance between anxiety and boredom resulting in feelings of agency, enjoyment, and accomplishment. Though Rieber contributed to the literature linking metacognition, playing, and game environments, he omitted raw conceptualizations of resonance between play and pursuits for self-actualization, agency, and knowledge–perhaps in an attempt to avoid the idealization of play, an unwanted notion that all play is good (Milne, 2012; Rieber; Smith, 1995)

I sought here not to idealize nor anthropomorphize play as an affecting agent of change, but to elucidate the profound transient significance play may have on the individual, the collective, and the environment. How are learners supposed to engage in metacognitive self-regulative tasks required for modern educational games (Rieber, 1996) if we restrict autonomy by confining play to only exist as instructional or game designers choose? I argued authentic play allows players to themselves shape the play-sphere in which they play alone or play with others. This notion goes beyond designing games for instruction and beyond constructivist learning-by-design in which learners become the game designers (Bonanno, 2010; Kafai, 2006). I situated play as an empowering medium through which learners actively participate in their own learning processes, simultaneously as individual unique agents and as community members working and playing together for personal and cultural growth. Such play may, in part, be achieved by entering a mental state of flow, when absolute focused motivation manifests (Csikszentmihalyi, 1990).

To be pragmatic, I paradoxically succumbed to the consistently changing notions of what counts as knowledge, education, and school. Reflective of utterances from centuries past, I regarded the core of play similarly to that of Plato, Schiller, Sutton-Smith, and Huizinga, while valuing Csikszentmihalyi's notion of flow as a profound variation on a theme of Piaget's play theory. Incorporating elements of Huizinga's play-factor of culture, Csikszentmihalyi (1990) viewed that, "games fill out the interludes of the cultural script" (p. 81). Just as music has been conceptualized as "the space between the notes" (Debussy as cited in Koomey, 2008, p. 96), games may provide learners with analogous socio-cognitive spaces. Well-designed educational games may have the capacity to guide learners to construct their own scripts about life, learning, and essentially to tap into and express their own agency.

Epistemological Foundations of Play

The nature of play is ambiguous and paradoxical (Sutton-Smith, 1995). Scholars researching play rarely venture into a domain outside the discipline of original study. Assorted disciplines retain ideas and methodologies about play within their own domain constructs. Consequentially, research from one discipline remains intra-disciplinary without interdisciplinary transference. From this stochastic state, play has been a malleable cultural form, vulnerable to multifaceted persuasions (Sutton-Smith). A medium for propaganda as a preliminary body of knowledge and rules, play must be more openly discussed, debated, and accepted across disciplines to better understand the epistemological foundations of play. Given the blurry boundary conditions of the nature of play, what are the evolutionary factors and the methods of gaming that may translate into productive learning experiences?

Human Evolution

Laden with controversy, the role of play in human development (Pellegrini, 2009) spans different domains. From an evolutionary standpoint, the manner in which the brain has evolved to control and organize movement may reveal how human cognition emerged (Llinas, 2001). Humans historically used play as a learning context for controlling and organizing movement and knowledge (Huizinga, 1938/1980). Games offer a natural framework for children to learn about action and effect, as controlled movements involve choice and temporal ordering (Tomporowski, McCullick, & Horvat, 2010). As a learning tool, play enhances personal, social, perceptual, and intellectual development (Macintyre, 2012). Humans naturally play upon fulfillment of basic needs (Sutton-Smith, 1995). Such play promotes self-realization and motivation "when superabundant life is its own stimulus to activity" (Schiller, 1794/1965, p. 133).

Play has been regarded as one of the most important areas of study for sociobiologists (Wilson, 1975). Contrastingly in evolutionary biology, play has been suggested as having no function (Sharpe, 2005) and in anthropology as having been purely wasteful (Caillois, 2001). From an anthropological standpoint, the play element of culture has factored into political and religious matters (Sutton-Smith, 1995). Further elucidating blurred intra-disciplinary conceptualizations of play, anthropologists have suggested that play is obligatory (Sutton-Smith). This constraint contrasts with the historical, philosophical, and educational theories of Huizinga, Schiller, and Sutton-Smith who have aligned with the stance that play must be voluntary.

From a psychological standpoint, engaging in serious play has supported natural survival by scaffolding the development of intelligence through observing others (Köhler, 1926). For humans, play has been grounded in practice and has been essentially processual (Malaby, 2007). Through imaginative play, for example, children learn (Zigler, Singer, & Bishop-Josef, 2004). An important factor for healthy child development, play (Ginsburg, 2007; Macintyre, 2012) mediates the transition from adolescence into adulthood (Bruner, 1972; Tomporowski, McCullick, & Horvat, 2010).

Biologically, playing in moderation has been associated with well-being (Fagen, 1981). And generally, those who moderately play tend to be mentally, physically, and socially healthier individuals (Macintyre; Sutton-Smith, 1995).

From a learning perspective, play is safer than real life. Fewer ramifications accompany play (Bruner, 1972), particularly in social settings (Millar, 1968). Consequences from losing a game, for the most part, remain inside the boundaries of the game space (Garris, Ahlers, & Driskell, 2002). Games offer players more freedom to learn from mistakes, errors, and failures (Gee, 2003; Veen & Staalduinen, 2009). Psychologists (Köhler, 1926; Sutton-Smith, 1966) and biologists (Fagen, 1981; Wilson, 1975) have linked play and creative responses to the environment for decades (Sutton-Smith, 1995). In the safe context of play for species with prolonged adolescence, youth place themselves into unconventional and disorienting situations. These new positions provide opportunities to explore various behavioral and cognitive practices and to create original and potentially adaptive responses. Individuals employ these processes with increased proficiency though repeated play experiences. Accordingly in times of need such as in emergencies, these processes become more accessible (Stamps, 1995). A means to develop alternative responses to novel and challenging environments at relatively lower costs, play has been important in evolution due to the enhanced learning associated with decreased risks (Pellegrini, 2009).

School Play as a Function of Human Beings

We have Piaget to thank for much of the play realized in school. Piagetian notions that play functioned to aid children's cognitive development (Piaget, 1952) have been connected to academic performance in school (Saltz & Johnson, 1974). For the preschool years in particular, educators attempted to incorporate play into school curricula (Pellegrini, 2009). Piaget's conception of cognition, however, minimized personal and collective agency by regarding that children within predefined mental stages cognize aspects of their world in parallel processes. Beyond Piaget's view that cognition was a central processing analogue (Pellegrini), schools have realized educational value, for example, in agentic make-believe play in literacy.

In activities for early literacy development, types of language that characterize pretend play and story time have proved successful by harnessing the power of narrative empowerment and decontextualized language use (Cochran-Smith, 1984). Developmental progressions of writing have been linked to preschoolers' symbolically transforming objects, such as a pen to represent a sword, in play (Galda, Pellegrini, & Cox, 1989; Pellegrini, 2009). The writing and pretend play in both studies exemplified Vygotskian first-order symbolization, in that both the writing and the pretend play represented objects instead of inert isolated words. For the preschoolers, the writing and pretend play were more graphic and more helpful than linguistic systems (Pellegrini). Proposed though empirically unsubstantiated, symbolic play benefits children in developing the skill to think hypothetically later in life (Harris, 2006).

Outside school walls, schools historically value recess to the extent that children's participation in games predict school adjustment and social competence (Pellegrini, Kato, Blatchford, & Baines, 2002). Achievement training has been associated with games of physical skill (Kenyon & Loy, 1965). Increased body size, improved chances of survival and social dominance, and even reproductive fitness all have been suggested to result from locomotor play (Pellegrini, 2009). At recess time in the play-sphere of the playground, children learn and develop important motor and social skills (Pellegrini), yet recess has been significantly cut from school days (Pellegrini & Bohn, 2005) in systems exalting the standardization of academics. Whether politically induced or culturally emergent, formal schools for the most part have valued standardized assessments (Pellegrini) with end results heavily prioritized over the means. As human societies have advanced to provide formal schooling for children, play has often been relegated to a non-academic yet important school-related activity despite the educational benefit of play.

Games as a Genre for Defining Contextual Learning Tools

Classification of games. As with play, what constitutes a game has no agreement (Garris, Ahlers, & Driskell, 2002; Salen & Zimmerman, 2004; Wittgenstein, 1958). The anthropologist Roger Caillois (1961) considered a game as an uncertain, voluntary, enjoyable, rule-governed activity separated from reality that produced no goods of external value. Abt (1987) considered a game to be any contest or collaboration between opponents or players who strived to meet an objective while operating under constraints. Cruickshank and Telfer (1980) defined a game as a contest, either academically or non-academically oriented, in which players abided by specified rules to gain a certain objective. A commonly adopted definition (McClarty et al., 2012; Schwartz & Bayliss, 2011) has been Salen and Zimmerman's, that a game was a "system in which players engage in artificial conflict, defined by rules, that results in a quantifiable outcome" (p. 80). Malay (2007) defined a game as a quasi-bounded and socially justified arena of arranged probabilities that produced interpretable outcomes. Connecting game notions with play, Malay's rendition of play was a state of mind into which people entered and games were socially structured practices that allowed entrance into a play-state (Bateman & Nacke, 2010). Along this idea, I regarded games as a medium through which play functions.

Games have been classified into four general categories based upon the function of the playing experience: *agon*, *alea*, *ilinx*, and *mimicry* (Caillois, 1961; Csikszentmihalyi, 1990; Loy & Kenyon, 1981; Rieber, 1996). Competition drives *agon* games. Games of chance are *alea*. Games that alter consciousness by distorting perception through physical exhilaration, such as vertigo induced activities, are *ilinx*. And alternative realities manifest in *mimicry*. Caillois further organized games with respect to an activity dimension with two extremes, varying from structured rule-based activities to unstructured spontaneous activities (Bateman & Nacke, 2010). From a contemporary industry standpoint, games have been further categorized as action, adventure, fighting, puzzle, role-playing, simulations, sports, and strategy (Herz, 1997;

Kirriemuir & McFarlane, 2004). From a 21st century global learning standpoint, games have typically been classified into the disciplines of digital entertainment, computer sciences, and games development (Edvardsen & Kulle, 2010).

Microworlds and simulations. Frameworks with potential to support game-based learning are microworlds (Papert, 1993; Rieber, 1996) and simulations (Rieber). In representing social (Rossiter & Reeve, 2010) or physical realities (Schwartz & Bayliss, 2011), a game may function as a simulation, microworld, or both (Rieber). Often associated with computers, microworlds allow users entry into a domain-specific world at increasingly sophisticated levels. Simulations represent environment models to which users would not otherwise have access. Games afford meaningful ways to present microworlds (Rieber; van Staalduinen, 2011) and simulations to learners (Rieber). Such environments provide opportunities for constructive forms of feedback (Squire, 2002), reflection, and revision, and also serve as representations and visualizations (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999)

In educational gaming research, simulations have typically been regarded as a subset of games described as functional representative systems of features of the real world (Guetzkow, Alger, Brody, Noel, & Snyder, 1963), as the resulting products from creating the effect of something else (Cruickshank, 1977), as process models relating input to output variables within a simplified version of reality unconstrained to definitive end points (Randel, Morris, Wetzel, & Whitehill, 1992), as emulations of imaginary or real systems or environments (Thurman, 1993), and as simplified situations or places recreated for a player to succeed in a task (Kirriemuir & McFarlane, 2004). Rieber

(1996) delineated the function between scientific and education simulations. Whereas scientific simulations enable scientists to refine theory, "educational simulations are designed to teach someone about the system by observing the result of actions or decisions through feedback generated by the simulation in real-time, accelerated time, or slowed time" (p. 49). Whether scientific or educational, a fundamental attribute of simulations and microworlds is the instructional opportunity to learn-by-doing (Barron et al., 1998).

The term "microworld" was originally coined in the field of artificial intelligence (Sarama & Clements, 2002) to describe a:

> *[S]mall, coherent domain of objects and activities implemented in the form of a computer program* and corresponding to an interesting part of the real world. Since the real-world counterparts were typically very complex, the microworlds of those early days were simplified versions of reality, acting as experiments to test out theories of intelligent behavior. (Weir, 1987, p. 12)

Conducive to play, the constructivist idea of a microworld (Martens, Diener, & Steffen, 2008) situates learners within a specific domain as part of the game environment in which players interact and explore complex ideas (van Staalduinen, 2011).

Found naturally or artificially, microworlds differ from simulations by encompassing qualities not necessarily found in simulations. In microworlds, learners enter a simplified version of a specific domain with opportunities to reshape the microworld's boundaries and to participate in increased sophistication and complexities (Rieber, 1996). Also, microworlds match learners' cognitive abilities, which simulations may not always do. Learners typically require no training to jump right into microworlds, which is why artificial microworlds tend to be more technologically advanced than simulations (Ellington, Gordon, & Fowlie, 1998). Accordingly to function in a microworld, learners practice the metacognitive skill of self-regulation (Rieber).

Unlike a microworld, a simulation is a high fidelity model of a specific domain. On the downside, novice users may not always find a simulation as easy to enter as a microworld. On the upside, a simulation provides direct access to a domain that would otherwise have been inaccessible in real life. A practical way to meet the metacognitive requirements for succeeding in a microworld is through coalescing simulations, microworlds, and games, as "Simulations offer a direct link to the subject matter or content; and games offer practical means for meeting the microworld assumption of self-regulation" (Rieber, 1996, p. 49).

Features of simulations can be transferred to microworlds, such as allowing the user to modify the simulation into a more manageable system. In this combined model, simulations-as-microworlds retain both scientific and educational properties. The framework of simulations-as-microworlds (Rieber, 1996) provide a helpful structure in designing effective game-based learning environments. Combining relevant features of simulations with microworlds may even help learning environments to benefit from Csikszentmihalyi's (1990) idea of flow and Piaget's (1952) notion of play.

Examples of educational games have ranged in scope and function, as shown in Table 2. This list provides only a glimpse of the educational games that are and have been employed in learning environments.

Table 2

Examples of Educational Games

Game Name	Description
Alien Rescue	A problem-based computer game of a terrestrial environment in which students rescue alien life forms, while learning astronomy and practicing science (Pedersen, 2003)
Amsyn Problem	A manual simulation game about chemical engineering (Percival & Reid as cited in Ellington, Gordon, & Fowlie, 1998)
Chemsyn	A card game based on organic chemistry (Heyden & Son as cited in Ellington, Gordon, & Fowlie, 1998)
Contract 3-5	A board game about business contracts (Fowlie as cited in Ellington, Gordon, & Fowlie, 1998)
Crystal Island	A science mystery microworld computer game in which students play microbiologists to gather and record information for their hypothesis (Ash, 2011)
Culraggie Whiskey Game	A board game about the whiskey industry (Edge, Ellington, Gordon, & Fowlie, 1998)
Extinction: The Game of Ecology	A board game about the survival of the fittest, based on Darwin's Theory of Evolution (Hubbell & Piret, 1970)
It's Your Turn!	A collaborative board game in which learners participate in social determinants of health, players engage in an agentic narrative journey through life dealing with macro (political, environmental, economical) and micro (financial, educational, family dynamical) issues (Rossiter & Reeve, 2010).
Minecraft	A two player computer simulation game using motivation and feedback to teach fractions by animating retrieval of a miner's axe (Persson, 2011)
Monopoly	A multi-player competitive board game designed to teach about the challenges of capitalism (Detar, 2015)
River City	A microworld computer game about inquiry in which teams of players create hypotheses and conduct experiments to solve why residents in an 1800's industrial town become ill (Ketelhut, Nelson, Clarke, & Dede, 2010)
Sandbox	A natural microworld, the original sandbox in which children have played for generations can manifest into a game environment if participant(s) choose (Categorization given by Rieber, 1996)
Starpower	A manual simulation game about the conflict and stratification that develop in an unregulated free-market (Ellington, Gordon, & Fowlie, 1998)
Supercharged!	A simulation computer game based on electrostatics in which players explore electromagnetic mazes and arrange charged particles to control a ship (Squire, Barnett Grant, & Higginbotham, 2004)

In playing educational games, learners are provided opportunities to develop new and situated conceptualizations via augmented experiences in complex domains that would be otherwise unapproachable (Gee, 2003; Wideman et al., 2007). Effective games embed information into the arena through which players navigate, illuminating the contextual and applicable meaning of the information for the constructs of the game space (Gee). Thus, the environment in which a game is played must be contextually relevant for learning to flow. We now explore qualities of learning environments conducive to productive play.

Learning Environments

A medium for problem-based learning (PBL), games provide learners opportunities to learn-by-doing in safer, more personalized, playful, and less constrained variations on themes of domain realities. Students using familiar materials more readily create their own ideas to build explanations (NRC, 2007). In modern day classrooms, students may feel more comfortable winning and losing in a game-related environment because such an environment is more familiar to those digital-age learners who are heavily exposed to the abundance of games outside of school (Williamson & Sandford, 2011). Since failure is of critical importance to learning (Gee, 2009; Klopfer, Osterweil, & Salen, 2009), games–and in particular simulations–may help learners to practice higher-order thinking skills and to act on decisions (Gee, 2003) in a safer environment, resulting in deeper learning (Gee, 2009).

For example, Schwartz and Bayliss (2011) have demonstrated how game and instructional design entirely overlap. Situated on the ethics of sustainability, their engineering course was a game on sustainability and the game was the course. Students generated products (desired grades), resulting in pollution (grade penalties), while overcoming competition via collaboration to learn how to balance personal and collective goals with outcomes. Instead of presenting real cases of engineering disasters in hopes to sway future engineers toward social responsibility, the game generated an immersive environment in which agents could make their own mistakes. Though not many students may think to intentionally cause harm (Bucciarelli, 2008), without transformative experiences for action learning, students may lose agency and become de-motivated. Such real-world problems anchor action learning for gaming (Rothwell & Kazanas, 2004).

Games invite learners to apply deeper levels of knowledge and skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956; Webb, 1997) such as strategic thinking, planning, communication, negotiation, group decision-making, and data-handling (Kirriemuir & McFarlane, 2004). Two common themes have driven the development of educational games: the aspiration to harness the motivational power of games to blend learning with fun, and the notion that learning-by-doing in games is a powerful learning tool (Kirriemuir & McFarlane). Insufficient for game-based learning implementation, traditional direct instruction (Prensky, 2007) suppresses the realization of educational gaming benefits. Therefore, facilitating a game-based learning environment requires embracing alternative modes of instruction beyond those traditionally employed.

Problem-based learning for game-based learning. Games aligned with learning-by-doing offer extremely effective learning experiences (Galarneau & Zibit, 2011). An instructional method for learning-by-doing, PBL is a comprehensive approach to education designed to replace traditional approaches (Barron et al., 1998) with blended learner-, community-, knowledge-, and assessment-centeredness (NRC, 2000). Modeling the process by which experts systematically work through real-life problems, PBL encourages learners to be responsive to encountered challenges and to take ownership of learning. With attributes such as self-regulated learning, agency, learning anchored to a larger problem, and collaboration, the PBL framework situates the instructional goal as the learner's need for knowledge and skills that highlight the connection of knowledge to contextually relevant applications (Barron et al.). A testament of efficacy, PBL has been successfully adopted by various academic domains such as elementary level mathematics and science (Barron et al.), secondary level astronomy (Petrosino, 2004); professional fields such as medical education (Kaufman & Mann, 1996), business schools (Milter & Stinson, 1995), and schools of education (Bridges & Hallinger, 1992); and architecture, law, engineering, and social work (Boud & Feletti, 1991).

A PBL attribute, self-regulated learning liberates students to acquire knowledge in the order and manner making the most sense to the individual. Self-regulation is a metacognitive process in which students learn to identify gaps in their own knowledge and to evaluate and assess their own strengths and weaknesses (Pintrich, Wolters, & Baxter, 2000). Self-regulatory abilities enable students to reflect on and actively participate in the learning process (Bandura, 2001). Unlike direct instruction techniques, self-regulation supports the identification and appropriate treatment of misconceptions as learning becomes more visible.

The sense of agency in PBL affords learners ownership of the process used to develop a solution (Savery & Duffy, 2001). With ownership of the problem itself, the solution process, and the result, agentic learners establish a relationship with the knowledge acquisition process that fosters authentic learning (Bandura, 2001). Throughout the problem solution process, learners may acknowledge that maintaining efficient work leads to the acquisition of more knowledge and skills. By presenting problems in an ill-structured implicit format, an educational game structures the learning process so that the problem, not predefined explicit directives, stimulates students' needs to know. With a sense of agency in the problem, students internalize the solution process (Bandura), as previously undeveloped knowledge and skills are cognitively attained in order to reach a satisfactory solution (Barron et al., 1998). Over time, this need to know generates the mental framework for cognitive flexibility (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999).

PBL activities are anchored to a larger task or problem (Barron et al., 1998). An anchor situates an activity beyond an assigned means to an end. The meaningfulness of problems can be enhanced by "drawing on ones that situate learning in the context of networks of ideas and practices" (Duschl, Schweingruber, & Shouse, 2007, p. 255). Anchors scaffold learners to clearly interpret activity relevance to the larger task. A driving question or game narrative exemplifies instructional anchors. A driving question in a project or game makes connections between activities and the underlying conceptual knowledge desired as the learning outcome (Barron et al.). By asking students an exploratory question about the problem at hand, driving questions and game narratives deepen students' understanding without the hindrance of confounding abstractions.

A fundamental PBL feature is collaboration (Barron et al., 1998). Solutions to real-world problems often require contributions from more than one person (Bandura, 2001). Many relevant problems in real life become resolved only through collaborative effects of several people who bring different perspectives, approaches, and prior knowledge to the problem solution process. An example of this collaborative attribute, small face-to-face group environments stimulate deep thinking by helping learners to develop higher intellectual skills, such as reasoning and problem-solving (Cohen, 1994). As opposed to a conventional instructional approach of a lecture with direct instruction, small group work enables learners to mobilize prior knowledge. Based on individualized prior knowledge brought to the group, learners support each other in actively constructing explanatory models. In turn, group-established models facilitate the processing and comprehension of new information and the updating of cognitive structures. Collaborative effects of small group work invite discursive elaboration and productive argumentation. When encouraged to elaborate on new information, learners better understand associated concepts. The collaborative activities involved in small group work help learners to construct rich cognitive models of the problems presented to them in ways unsupported by conventional curricular approaches (Cohen; Rossiter & Reeve, 2010).

Aligned with self-actualization, agency (Ellis, 2004) promotes an educational experience in which the individual freely aspires to achieve desired goals. Anchored learning locates the interests of the individual students as the directive of the learning process. Further, collaboration harnesses social learning that fosters agency associated with productive play (Podolefsky, Rehn, & Perkins, 2013). These PBL principles extend to game-based learning by helping learners develop the kinds of knowledge representations, modes of thinking, and social norms that contribute to successful domain learning indicative of meaningful learning necessary for doing with understanding (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). Instead of rote memorization for inert regurgitation of facts, students do with understanding when authentically participating in one's own learning.

Doing with understanding. Four interrelated attributes of learning environments required for doing with understanding are learner-, knowledge-, assessment-, and community-centeredness (NRC, 2000). Learner-centered environments pay careful attention to the knowledge, skills, attitudes, and beliefs that learners bring to the educational setting. Inclusive to culturally relevant instructional practices, instruction facilitating a learner-centered environment gives students incentive to learn by respecting and understanding prior experiences and understandings through acknowledging that these serve as a foundation on which to build bridges to new understandings. Knowledge-centered environments focus on the kinds of information and activities that help students develop an understanding of disciplines. With an emphasis on sense-making, a knowledge-centered environment requires that attention be given to what is taught, why it is taught, and what competence looks like. Assessment-centered environments provide opportunities for feedback and reflection. What is assessed must be congruent with the learning objective(s). Given the procedural nature of games, for example, an assessment scheme prioritizing the learning process over end results would be more appropriate for game-based instruction. Though both summative and formative feedback are needed for doing with understanding, formative assessments are particularly essential because they help both teacher and student monitor progress. Situating learning within the context it takes place, a community-centered environment embraces the development of norms for the classroom and school, as well as connections to the outside world that support core learning values. Following suit, activities within schools must be aligned with the goals and assessment practices of the community to foster doing with understanding.

Meaningful learning with achievable goals. Effective learning environments provide meaningful learning with achievable goals–that is, goals with manageable difficulty, where goals are still challenging enough to evoke interest. This appropriate level of challenge empowers students to take charge of their learning (Duschl, Schweingruber, & Shouse, 2007). When instruction is designed for meaningful learning and appropriate goals, students implicitly map out prior knowledge to apply in new contexts and to make appropriate adaptations. Supporting flexible use of knowledge and transfer to establish a deep understanding, this learner-centered principle aims to engage students in individual learning processes (NRC, 2000) by maintaining motivation and interest (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). Environments supporting this principle present students with a platform on which to build deep learning skills.

With meaningful learning, students cognitively represent knowledge frameworks in coherent, accessible, and flexible systems. Knowledge has been regarded as not "inert" (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999, p. 604), but as vibrant quanta of information reacting with socio-cognitively formed knowledge schemas. Cued by subtle nuances of this knowledge chemistry, learners self-identify relevant knowledge transmission. Such interconnected and coherent knowledge promotes meaningful learning and the development of appropriate goals (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt). When in the context of solving problems, deep thinkers learn to apply relevant information. In applying situational knowledge connected to circumstances, such as on-the-job or game-related tasks, knowledge becomes more reactive (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt). When knowledge has an identifiable context, the associated goals within that context become more realistic (Bandura, 2001; Brown, Collins, & Duguid, 1989) and thus more relevant to learner interests.

Scaffolding. Scaffolding has been defined as the "additional support built around a core version of a task to make it more tractable and useful for learning" (Duschl, Schweingruber, & Shouse, 2007, p. 272). Analogous to the actual infrastructure of a building, scaffolds furnish temporary frameworks within which deep understanding and learning occur. The instructional framework serves as a cognitive tool for students to structure learning. Key components to scaffolded instruction are sharing a common goal, ongoing diagnosis and adaptive support, dialogues and interactions, and fading and transfer of responsibility (Puntambekar, 2009).

Meaningful problems encountered in games involve complexities not encountered in traditional classroom tasks. Scaffolding deconstructs complexities into manageable segments, where the complex task may be solved by working though the knowledge components of the smaller segments, while maintaining segment cohesion. Scaffolding makes complex processes, such as scientific processes, more explicit by providing an appropriate learning structure. A scaffolded task affords students means to learn about concepts in increasingly sophisticated contexts building upon previously scaffolded steps. Educational games may embed instructional guidance in complex tasks by scaffolding process, social interaction, conceptual models, articulation, reflection, and assessment (NRC, 2007). When brought together, these "complementary aspects of science" engage "learners in such practices as investigation, argumentation, explanation, and model building" (Duschl, Schweingruber, & Shouse, 2007, p. 285).

Complex processes are scaffolded by developing an instructional framework, usable throughout the duration of the project or game, to help students organize proficiencies in their own way. Scaffolding games helps students manage the challenges encountered in complex scientific learning environments (De Jong & Van Joolingen, 1998). Scaffolding techniques, such as Vygotsky's Zone of Proximal Development, minimize the distance between learners' actual levels of development and potential levels of development (Vygotsky, 1978). Acting more like experts, students gradually learn to deeply think on their own, with less and less structural support for thinking. These peer interactions are essential for successful scaffolding in the classroom setting (Puntambekar, 2009). Other examples of scaffolding include interactions with more knowledgeable others, modeling and prompting, increasingly complex microworlds, problem-based to project-based inquiry, and visualizations and representations.

Fostering flow. A well-designed game is challenging, but achievable (McClarty et al., 2012), with a balance of fostering a flow state (Csikszentmihalyi, 1990). When students authentically play an educational game, they play for the sake of playing in the spirit of fun. As self-consciousness dissipates, the gravity of serious and gratifying concentration warps time supporting a state of flow that "provides a sense of discovery, a creative feeling of transporting the person into a new reality" (Csikszentmihalyi, p. 74). With a positive impact on learning, flow has been argued as the desired outcome of a game (van Staalduinen, 2011). Key antecedents of flow in games have been found to be clearly defined rules and goals, active player feedback, and a sense of control players have over the game (Kiili, 2006; van Staalduinen).

Csikszentmihalyi (1990) has proffered that through play and flow, the self can be transformed into an existence of heightened complexity. Flow functions as a powerful motivator, yet does not always guarantee virtue for those who experience it. To make flow possible, agents must restructure consciousness (Csikszentmihalyi). The self at play has essentially been conceptualized as striving to restore the imperfections of being unempowered but mortally confined; play cathartically reminds us that life has a present, a future, a currency, and can be lived (Sutton-Smith, 1995).

Sociological Foundations of Play

When a culture manifests goals and rules so intensely resonant with the population's abilities to the extent that members frequently experience flow, distinctions between culture and games dissolve (Csikszentmihalyi, 1990). Games are social artifacts (Malaby, 2007). The types of games people play reflect the inherent values of a particular culture (Kenyon & Loy, 1965; Sutton-Smith, 1995) and at the same time serve to teach certain cultural values and attitudes. In a stable group, the social constructions derived through play tend to endure as group traditions (Sutton-Smith). We now realize the significance of others in learning environments and the value of peer interactions for cognitive and social outcomes (Pellegrini, 2009) developed, in part, by social learning and scientific productive participation.

Social Learning

In the second half of the 20th century, the field of education evolved not only from the "cognitive revolution," but also from a shift in social learning which relocated "individual cognitive functioning within its social, cultural and historical contexts" (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999, p. 596). With the advent of the "cognitive revolution," social learning emphasized the importance of cognitive processes, rather than just conditioned responses (Bornstein, 1993). Accordingly, social learning has been deemed the learning associated with experiencing an environment with others, where progress difficult to attain by individual means more easily occurs.

Metacognition, motivation, and competence do not alone dictate successful implementation of intentions, for “most human pursuits involve other participating agents” (Bandura, 2001, p. 7). In the social learning of social cognitive theory, agency has been depicted as flowing along triadic reciprocal causation between nodes of behavioral, personal, and environmental factors (Bandura, 1986). For example, when playing in a group as opposed to playing alone, players prompt each other to think in new ways, provide feedback, share a sense of collective agency, and participate in emergent discussions leading to unforeseen answers collectively envisioned by the group (Rossiter & Reeve, 2010). Thinking may be made visible through spontaneous dialogue, in which small groups of players engaging in high-level discourse can be attributed as productive (Vygotsky, 1978). In this respect, the problem-solving model of making thinking explicit does not deemphasize the ongoing social nature of understanding, as has been asserted (see Cohen, 1994), but fuels social learning by providing conversational scaffolding in the group discourse of decision-making. Emphasizing the centrality of activity in learning and knowledge and highlighting the inherently context-dependent, situated, and enculturating nature of learning, situated cognition theory (Brown, Collins, & Duguid, 1989), as well as social cognitive theory (Bandura, 1986, 2001), have advanced collaborative social interaction and the social construction of knowledge for an improved educational epistemology.

Collaboration. Learning has been defined as a process of enculturation that supports collaboration through collective problem-solving, displaying multiple roles, confronting ineffective strategies and misconceptions, and providing collaborative work skills (Brown, Collins, & Duguid, 1989). Goldman, Petrosino, and the Cognition and Technology Group at Vanderbilt (1999) classified collaboration as an important component in learning principle design. The concept of collaboration differs from traditional direct instructional methods, where teachers systematically present material in quantized steps. Different students have different mental constructs and unique ways of applying cognitive processes. Standardized instruction may not resonate the most efficiently with all students' learning and may stimulate only a narrow range of cognitive functioning. By collaborating, students tailor learning processes to the homeostasis of the group and to personal utility functions, which invites more open dialogue. With a wider range of appropriate discussion, students are afforded more opportunity to stimulate different cognitive processes. In turn, this increased cognitive functioning induces knowledge acquisition. Collaborative gaming promotes such varying degrees of interactional organization (Bonanno, 2010).

Cognitive learning shifts towards a socially oriented learning scheme when instruction is arranged to promote collaboration, distributed expertise, and entry into a discourse community of learners (Goldman, Petrosino, & Cognition and the Technology Group at Vanderbilt, 1999). Collaborative learning environments turn complex individual tasks into a manageable group experience. This community-centered principle functions like a pair of prescription glasses for learners to more clearly understand feedback, revision, and reflection. The social learning of a group atmosphere makes visible individual thinking styles, where the role of feedback becomes a two-way street as group members both give and receive feedback (Goldman, Petrosino, &

Cognition and Technology Group at Vanderbilt). When instruction is arranged to promote distributed expertise, the group as a whole may realize that every group member serves a purpose and a unique feedback perspective. With a defined need, learners function more like experts and engage in the discourse of decision-making. Articulation, reflection, and representation (Duschl, Schweingruber, and Shouse, 2007) have been regarded as vital to the success of the collaboration involved in the productive argumentation of decision-making. Students must be engaged in such nature of science practices to form their own epistemic foundations of authentic domain knowledge (Sandoval, 2005), specifically scientific knowledge.

Scientific representation and modeling. Building representations and models, as well as engaging in scientific discourse, helps students understand that scientific knowledge takes a variety of different forms (Sandoval, 2005). In building and testing theories, the practice of science is governed by efforts to invent, revise, and contest models. Model usage is an important way scientists make their thinking visible.

Representation precedes modeling. A model is the collection of features of a phenomenon for which a representation accounts or fails (NRC, 2007). The use of forms of symbolic representations, such as graphs, tables, mathematical expressions, and diagrams, can be developed in learners and lead to more sophisticated modeling in later years (NRC). Modeling involves construction and testing of representations analogous to real-world systems. Such representations take many forms, including physical models, computer programs, diagrams, mathematical equations, and propositions. A key concept is for students to understand that models are not intended to be exact copies; they are deliberate simplifications of more complex systems.

Mathematics gives scientists a system for sharing, communicating, and understanding concepts. For scientists and also for science learners, expressing an idea mathematically may result in the discovery of new patterns or relationships that otherwise might not have been seen. Examples include equations, graphs, and corresponding units. Inherently abstract observations that stand for concrete events, data are represented in various ways to see, understand, or communicate aspects of the phenomenon of study. Data collection and interpretation entails finding and confirming relationships, which may have varying levels of complexity. Scale models, diagrams, and maps are also examples of modeling, highlighting that form follows function.

The ease with which students understand models and representation depends on the complexity of the relationship being communicated. Learning progressions developed for different grade levels emphasize different and increasingly complex ideas in different grade bands. Through learning progressions, students learn to use representations that are progressively more symbolic and mathematically powerful. When realized in the classroom, representations and the rich discussions they support open an important window into how students think about the phenomenon being studied. Modeling data is a fertile ground for advancing complex learning. Although working with representations and models poses challenges for learners, it can also help bridge the knowledge and skills brought into the classroom with more sophisticated scientific practices (NRC, 2007).

Though some schooling attempts to promote higher-order thinking skills, much of the inventive heuristics students bring to the classroom remain neglected. The modeling and representation associated with games may help teachers tap into students' prior knowledge. Games can be profoundly social representations. In playing games, making thinking visible becomes a group effort within a social learning environment. Because knowledge is coded by and connected to the activity and environment in which it develops, the environment plays a critical role in the indexical representations people construct in activity (Brown, Collins, & Duguid, 1989). Activities leading to indexical representations are central to learning, as knowledge indexes the situation in which it arises. Learning methods embedded in authentic situations, such as in games, are essential for meaningful learning (Brown, Collins, & Duguid).

Productive Participation

Successful implementation of productive participation in specific domains, such as in science, promotes intellectual progress (Duschl, Schweingruber, & Shouse, 2007). Participation in scientific practices guides students to proactively enhance an understanding of argumentation; to construct evidence, representations, and models; and to reflect on learning (Duschl, Schweingruber, & Shouse; NGSS 2013). Through productive participation, learners find solutions to ill-defined problems by engaging in systems thinking and complex communication (Windschitl, 2009). Productive participation further supports learners in developing important 21st century abilities (NGSS; Windschitl).

Science-as-practice. In contrast with an abundance of research that has often treated aspects of scientific proficiency as discrete, current research has suggested that proficiency in one aspect of science closely relates to proficiency in others (Duschl, Schweingruber, & Shouse, 2007). Addressing the knowledge and reasoning skills that students must eventually acquire to be considered proficient in science, the strands of scientific proficiency have been defined as the practices students need to participate in and become fluent with in order to develop scientific proficiency (Duschl, Schweingruber, & Shouse). The interconnected strands of scientific proficiency lay out broad learning goals for students, regarding science-as-practice.

The science-as-practice perspective invokes the notion that learning science involves learning a system of interconnected ways of thinking in a social context to accomplish the goal of working with and understanding complex ideas. Students proficient in science: know, use, and interpret scientific explanations of the natural world; generate and evaluate scientific evidence and explanations; understand the nature and development of scientific knowledge; and participate productively in scientific practices and discourse (Duschl, Schweingruber, & Shouse, 2007, p. 37). Multiple strategies of instruction are needed in the classroom, with some focused on specific knowledge, a particular conceptual understanding, or key skills related to critical thinking, metacognition, or scientific argumentation. Games anchored on a science-as-practice model afford students situated experiences for authentic practice that tap into scientific proficiencies. Enculturating students into authentic practices via social interaction and activity sustains domain learning by enabling students to acquire, develop, and apply cognitive tools in contextually relevant domain activities (Brown, Collins, & Duguid, 1989).

Argumentation. Essential to engage in learning-by-doing discourse (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999), argumentation is critical for learners to process, make sense of, and learn from their ideas (NRC, 2007). Encouraging argumentation invites articulation and reflection. Representing ideas through talk and argument plays a critical role in learning–and students need opportunities to talk through their ideas and to engage in argumentation (NRC). Games directly and feasibly present such discursive opportunities (Rossiter & Reeve, 2010).

Rarely observed in classrooms, productive argumentation is a fundamental discursive activity of scientists (Bazerman, 1998) "in communities of practice for the purpose of persuading colleagues of the validity of one's own ideas and the ideas of the others" (Duschl, Schweingruber, & Shouse, 2007, p. 187). A central component to scientific thought, argumentation (Duschl, Schweingruber, & Shouse) is a critically important 21st century skill. Components of productive argumentation include sharing, processing, observing, defending, rebutting, claiming, articulating, reflecting, and asking (NRC, 2007). With the goal to reach a point of mutual understanding or consensus (NRC), argumentation calls for articulating claims and deconstructing ideas when disagreement or divergence among competing claims manifests (Duschl, Schweingruber,

& Shouse). When confronted with a rebutting persuasive claim, a productively participating learner integrates the counter thought into their thinking with the help of argumentation in a community of learners.

Productively participating in learning largely involves negotiation and argumentation, which gaming easily transfers (Bonanno, 2010). When students talk directly with each other, productive argumentation in classroom settings is more likely to occur (Palincsar, Anderson, & David, 1993). However, students need the guidance for argumentation that traditional instruction lacks (Duschl, Schweingruber, & Shouse, 2007), such as opportunities to think aloud or engage in exploratory talk (NRC, 2007). Collaborative educational games cultivate argumentation by supporting metacognition, motivation, social learning, and scaffolding to depart from restrictive traditional learning conditions. In particular, face-to-face traditional board games offer opportunities for productive argumentation, as live discussion stimulates higher-order complex thinking skills (Rossiter & Reeve, 2010). Such “board games offer tremendous pedagogical promise for learners to critically engage complex, multifaceted social problems that mark contemporary life” (Rossiter & Reeve, p. 332). Through participating in productive argumentation while playing a game, students are guided to articulate their ideas and to discover that explanation–not facts–is the goal of the scientific enterprise (Duschl, Schweingruber, & Shouse).

21st Century Abilities

Twenty-first century instruction entails teaching students about complex systems, to participate in authentic domain practices, and to self-regulate learning (Windschitl, 2009). Educational games have been (Gee, 2003), can (Rossiter & Reeve, 2010), and will continue to teach the 21st century abilities (McClarty et al., 2012) needed to thrive in a consistently changing world. These global abilities include emergent technology use, problem-solving, communication, collaboration, (Levy & Murnane, 2004), critical thinking (Darling-Hammond, 2010), strategic thinking, planning, reasoning, (McCarty et al.), complex decision-making (Squire, 2006), and procedural thinking (Johnson, Smith, Willis, Levine, & Haywood, 2011).

Teacher preparation programs in countries with the highest quality education systems focus on a curriculum for preservice teachers to learn how to teach the 21st century skills needed in a technological global economy (Darling-Hammond, 2010). Skills needed to succeed in video games are commonly sought by employers (Federation of American Scientists, 2006). For example, the massively multiplayer online game *World of Warcraft* requires players to utilize key 21st century skills such as leadership, teamwork, communication, distributed expertise, multitasking, and collaboration to meet a common goal (Gee, 2005). Digital multiple player role-playing games espouse learning-by-doing and problem-based learning due to the affordance of seeing actions play out faster than real time would allow (Qui, 2010).

By processing information nonlinearly and abstractly, digital-age learners tend to think differently than traditional learners (Prensky, 2001). Higher-order thinking is required for 21st century learning–at the root of which is the ability to think abstractly. Those who play well-designed games, whether manual or digital, engage in abstract thinking (Johnson, Smith, Willis, Levine, & Haywood, 2011), for authentic play is abstract in nature (Huizinga, 1938/1980; Plato, trans. 1997; Schiller, 1794/1965).

Cognitive Foundations of Play

In the 1940s, a trend emerged among social scientists, logicians, and mathematicians that paralleled human thinking with computer processing (Gardner, 1987). At academic conferences such as the Hixon Symposium, scientists demonstrated the human brain could be thought of as a powerful computer (Gardner). To study such phenomena in psychology, the behaviorist climate of the field needed modification to provide for the means to conduct such research on cognitive processes. In the mid-20th century, the community of psychological sciences shifted from a behaviorist perspective, where only directly observable behavior was considered valid grounds for research, to a cognitive perspective, where any internal mental process indefinable as outwardly behavior could be accepted as valid grounds for study (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). This shift, the “cognitive revolution,” broadened the arena of modern research to include studies of the inner workings of the human mind. The “cognitive revolution” did not replace behaviorism, but brought about inclusive classification of cognitive processes. Reflected in the “cognitive revolution,” knowledge is “…viewed as an active construction by learners through interaction with their physical and social environments though the reorganization of their own mental structures" rather than "knowledge being something to be received, accumulated and stored" (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, p. 596).

Central to understanding the design of games is recognizing how games affect cognition. Neuroscientific researchers, for example, have suggested that play needs to be examined as an emotional and cognitive activity (Bateman & Nacke, 2010). Piaget (1952) regarded play as basically assimilative, which left no space for any cognitive benefit (Sutton-Smith, 1966). In this regard, play adapts to the world of the player (Smith, 1995). Cognitive foundations of play, however, afford more agency to the player in that a player indeed can change through play.

Best comprehended with respect to the quality of the player's subjective experience (Sutton-Smith, 1995), play has been conceptualized as a projection of one's own views about one's future (Vandenberg, 1988). The first step in willing something to be, the imaginative act of playing has been conceived as a "primordial form of wishing" that has the "conative (willing to be) side of foresight" (Sutton-Smith, p. 292). Such intrinsic motivation facilitates the flow experience in games (Gee, 2003; Salen & Zimmerman, 2004). Metacognition, for example, supports learners to internally process information and self-reflect on mental processing.

The Self-regulated Learning of Metacognition

Flavell (1976) regarded metacognition as "the active monitoring and consequent regulation and orchestration of [cognitive] processes" (p. 232). Just as there are cognitive mechanisms catalyzing language, there are cognitive mechanisms catalyzing play. The ludic challenge and goal-directed drive of educational games provides motivational mechanisms for self-regulation of metacognitive skills that support learning by play.

Through metacognition, learners reflect on personal performance from self-regulation, that is, the ability to orchestrate one's own learning (NRC, 2000). A cognitively inherent aspect of learning, self-regulation includes planning, goal setting, monitoring, self-evaluation, and behavioral activity, such as structuring the learning environment to suit one's learning style (Zimmerman, 1995). To regulate learning goals and activities, learners need to utilize sound self-monitoring skills (NRC, 2005). Features of games, narrative frameworks and goals requiring metacognition (Muwanga-Zake & Frank, 2010) increase self-esteem, for example, through extrinsic motivation when a player earns a reward such as winning a game (Rieber, 1996). Focused on an internally driven function instead of outwardly, intrinsically motivated self-regulated play attracts students to domains such as science and supports players in taking ownership of learning (Muwanga-Zake & Frank, 2010).

Instruction that provides opportunities for practice with feedback, revision, and reflection, teaches learners how to develop metacognitive self-monitoring skills. Without feedback, learners may not discover underlying misconceptions. Instruction with feedback is essential to communicate to students the status of their learning, so that students can take action as need be. Games that illustrate social constructs as dynamical representations, as in *SimCity* for example, employ feedback loops fundamental to complex and systems thinking (Squire, 2002). Research has shown that proficiency in complex systems thinking involves analyzing conditions, adapting strategies, and reflecting on actions (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). Games like *SimCity* provide players opportunities to practice this higher-level thinking.

During revision processes, learners actively update their learning structure, adapting new knowledge, prior knowledge, and knowledge infrastructure to more accurately reflect a concept. Reflective strategies require learners to correlate the big picture with feedback and revision processes. Reflective strategies for approaches to difficult problems (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999) entail self-regulation. A learner with metacognitive knowledge and skills, however, requires motivation, competence, and agency to actually engage in self-regulated learning (Zimmerman, 1995).

Motivation and Self-determination

The voluntary nature of play affords the necessary motivation for players to persevere, exploring novel routines where the journey is valued and not just a predetermined end result (Pellegrini, 2009). Attaining such a flow state, however, requires self-determination (Csikszentmihalyi, 1990). Self-determination (Deci & Ryan, 2000) involves more than simply choice, for choice is mainly a theoretical construct about play and not a satisfactory description of the motivation in play (Sutton-Smith, 1995). The motivation inherent in self-determination has been depicted as the synthesis of goal-directed behavior, the cognitive factors of psychological development and well-being, and psychological needs (Deci & Ryan).

Psychological needs for competence, relatedness, and autonomy need to be addressed in game design to understand the content and the process of pursing goals. When satisfying these needs, a person integrates personally identified regulations promoting both intrinsic and extrinsic motivation (Deci & Ryan, 2000). Deen and Schouten (2011) proffered that games affect players' "motivations to learn for the better" (p. 331) when games are designed to promote identified regulation (Ryan & Deci) instead of the common external regulation design basis (Deen & Schouten). Negotiations with personal utility functions and moral goals, identified regulations (Ryan & Deci) motivate players to learn during and even after a game (Deen & Schouten).

Games motivate (Ecker, Müller, & Zylka, 2011; McClarty et al., 2012) personally (Gee, 2009) and socially (Deen & Schouten, 2011). When a player feels a personal attachment to the goal of the game, motivation ensues (Gee). In this regard, educational games help personalize learning. Much educational play simulates real-world experiences to function as a consoling phenomenon, supporting players to realize increasing competence in abilities to manage a similar situation if encountered in real life (Galarneau, 2005). Situated life experience, whether virtual or real, offer learners opportunities to succeed in solving future problems (Brown, Collins, & Duguid, 1989). By meaning making through experiential learning based on direct experience (Kolb, 1984), players benefit from repeated exposure to various scenarios that promote competence.

Assessing learning in motivating contexts that are simultaneously socially and cognitively demanding increases the probability of triggering a player's competence. Socio-cognitive activities, such as authentic gaming, invite learners to reorient participation in experiences from passive undergoes to agents of fulfilling experience (Bandura, 2001). Agency entails those abilities to interact with others or materials and to feelings of belongingness related to socio-emotional support (Jalongo, 2007). Simple exposure to a problem does not alone motivate learners to become personally engaged. Rather, "agentic action in exploring, manipulating, and influencing the environment" (Bandura, p. 4.) regulates motivation required for the basic needs of autonomy and competency (Ryan & Deci, 2000).

Embedding an educational game in a social context may satisfy needs for competence, relatedness, and autonomy (Deen & Schouten, 2011). These needs have been identified as enjoyment predictors in game play, while perceived in-game autonomy and competence have been associated with game enjoyment (Ryan, Rigby, & Przybylski, 2006). Competence and autonomy perceptions have also been related to the intuitive nature of game controls and the sense of presence or immersion in players gaming experience (Ryan, Rigby, & Przybylski). Clearly, gaming satisfies learners' needs of competence, relatedness, and autonomy when under learning conditions that support identified regulations (Deen & Schouten). Unfortunately, most educational games are driven by business models for financial gain and not by instructional models for meaningful learning (Bonanno, 2010; Deen & Schouten).

State of the State: Research on Educational Gaming

Situated in social contexts, games (Squire, 2002) are bound by economic, political, and historical inertia that marginalizes educational play. Fortunately, games are situated in social contexts and thus help make learning relevant to more students. Culturally entangled, play provides opportunities for researchers of varying backgrounds and philosophical stances to transform educational constructs. Propagating new ways to advance how we conceptualize play and society, games have entrenched cultural awareness to an unprecedented degree (Malaby, 2007). We now trace the story of educational gaming through recent past, present, and potential realities.

Game Design and Instructional Theories

Educational game developers often start from scratch when designing a game and do not build on research standards (Maciuszek & Martens, 2010). Research standards are not prolific (Bonanno, 2010; Williamson & Sandford, 2011). Most game designers approach game-based learning by prioritizing the game design above the instructional design (Bonanno). The boundary conditions related to learning theory for educational game design are ill-defined and implicit. Without strong connections to learning theory, the web of instructional gaming will continue to be tangled.

Game designers have plenty of learning and instruction theories from which to choose. Beginning in the latter half of the 20th century, powerful theories of learning emerged with contextualization resonating important notions of effective game-based learning, such as reflection, authenticity, collaboration, learning-by-doing, flexible thinking, problem-solving, and decision-making (Kiili, 2007; Kirriemuir & McFarlane, 2004). Progressive theories such as problem-based learning (Barron et al., 1998), social leaning, situated cognition (Brown, Collins, & Duguid, 1989), and social cognition (Bandura, 1986, 2001; Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Zimmerman, 1995), identified learning scenarios and environments to which games may be conducive in fostering (Rieber, 2001). Towards the end of the first decade of the 21st century, learning theorists and educators increasingly acknowledged games as useful instructional tools and had begun to associate play as an important venue for 21st century learning (Kinzie & Joseph, 2008; Squire, 2002).

Games precipitate and catalyze learning (Oblinger, 2006). By engaging players to learn-by-doing, games foster authentic knowledge constructions and provide the field of education with learning scenarios directed away from the fragmentation of inert facts towards meaningful learning. Educational games support the development of 21st century skills (Williamson & Sandford, 2011) such as logical thinking, problem-solving (Whitebread, 2001), critical thinking and other forms of higher-order thinking (Prensky, 2001), and metacognitive abilities (Bonanno, 2010; Kim, Park, & Baek, 2009; McClarty et. al, 2012). In response to the globally realized positive learning outcomes associated with game-based learning (Kirriemuir & McFarlane, 2004; McClarty et al.; Oblinger; Prensky), educational literature has called for the research and development (R&D) of games (Kiili, 2007; Kirriemuir & McFarlane; VanEck, 2006; Rieber, 2001) created with respect to a learning theory (Kafai, 2006; Rieber, 1996; Schwartz & Bayliss, 2011) and to pedagogy and game design (Bonanno; Kebritchi & Hirumi, 2008; Williamson & Sanford).

Educational gaming as a research field is still in an early phase of development. Its presence already exists in the body of literature within education and gaming, though limited it may be (Wideman et al., 2007) and particularly restricted to digital games. The majority of studies in the literature are attached with digitized game-based learning, with the argument that, "The time has come to couple the ever increasing processing capabilities of computers with the advantages of play," (Rieber, 1996, p. 43). Little research exists exclusively on an instructional theory of games or play, with most simply stating learning goals as specific domain content knowledge acquisition. Researchers have reported few educational games designed with respect to a learning theory (Bonanno, 2010; Kafai, 2006), as "pedagogy and game design currently seem to be two separate worlds" (van Staalduinen, 2011, p. 98).

The Messy Arena of Play and Educational Gaming

The popularity of the notion, potential, and generalization of games has continued to grow, though traditional schools of thought stereotype gaming as an invalid form of education (Rieber, 2001, 2006; Williamson & Sanford, 2011). A negative stigma that games do not respect learning hinders research in gaming (Bonanno, 2010; Squire, 2002), adding to the lack of cohesion among academic fields about what an educational game actually is and does. Even definitions of instruction design–itself an interdisciplinary field (VanEck, 2007)–and learning vary throughout studies and time. In general, basic terminology is inconsistently used throughout the literature. The functions of the words “play,” “serious,” “fun,” and “game” often differ between researchers who commonly omit any philosophical or epistemological stance on play or gaming needed to convey research (Squire).

Some researchers have indicated that games do not improve learning outcomes (Wentworth & Lewis, 1973), while others have suggested the opposite (Kiili, 2007; Macintyre, 2012; Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011; Whitebread, 2001). Though game-based learning has been gaining momentum, the literature base has sustained a literature gap that empirically demonstrates the educational benefits of games (Randel, Morris, Wetzel, & Whitehill, 1992; Squire, 2002; Williamson & Sandford, 2011). Too few researchers have reported studies in which game-play has been examined (Squire). Much of the evidence in the literature deals with pre- and post-tests (see Schwartz & Bayliss) or qualitative interviews. Studying actual game-play is time consuming and difficult to achieve, which could be a reason why such data is absent from the literature.

Games and How People Learn

Games harness qualities reflective of how people learn (Oblinger, 2006). By playing games, children learn to think flexibly (Whitebread, 2001), collaboratively, and reflectively (Kiili, 2007), due to playing requirements such as recalling prior learning, constructing new knowledge, and decision-making. Successfully implemented game-based learning employs basic principles of problem-based learning (VanEck, 2007): contextuality, collaboration, and experientialism (Boud & Feletti, 1991). Gaming models, such as problem-based gaming, capture the authenticity of learning tasks, collaboration, and experiential learning (Kiili). Regarded as highly important in facilitating higher order-thinking skills, authentic learning situations anchor knowledge construction into meaningful real-life problem-solving scenarios (Brown, Collins, & Duguid, 1989). For some efforts of contemporary educational reform, games have served as such situated anchors to hook learner's interests (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999).

Games exemplify situated learning and cognition (VanEck, 2007). Contextualization and experientialism of situated learning theory (Brown, Collins, & Duguid, 1989) support the ability to transfer new knowledge and skills into applicable practices (Savery & Duffy, 1995) within educational games (Rieber, 1996; VanEck). Contextualized knowledge has been regarded by many education researchers as useful knowledge, since the learner needs to know when, where, and how to utilize such knowledge (NRC, 2000). Flexible, collaborative, and reflective thinking coupled with authentic and contextualized environments are crucial for meaningful learning (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). Problem- and project-based learning, activities under which game-based learning is considered, have rapidly increased as a way for learners to acquire and apply contextualized domain knowledge due to the established benefits of meaningful learning (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt).

Educational Gaming in Practice

Under the umbrella of PBL aligned with learning-by-doing, game-based learning demonstrates tremendous potential to further bridge the classroom practicality of educational gaming with the philosophical and epistemological foundations of play. How and if a game should be used for instruction depends on the domain (Randel, Morris, Wetzel, & Whitehill, 1992). Literature across domains–with prevalence in medical and business education (Wideman et al., 2007)–and for ranging age groups infers the effectiveness of game-based learning, for example, to encourage various cognitive (Prensky, 2001) and psychomotor skills (Dempsey, Rasmussen, & Lucassen, 1996; Piaget, 1952), to strengthen spelling and decoding performance in kindergarten students (Din & Calao, 2001), to help primary school students with poor reading skills (Schwartz, 1988), to increase language proficiency in middle-school students (Herselman, 1999), to teach challenges of economic systems (Detar, 2015), to collaboratively teach significant indicators of health through discourse (Rossiter & Reeve, 2010), and to teach ethics of sustainability in higher education (Schwartz & Bayliss, 2011).

During the Great Depression and subsequent recovery, academic and school libraries facilitated educational games for teachers to use in classrooms (Nicholson, 2013). In the 1980's, the U.S. implemented game-based learning for military training (Frank, 2012). Learning from play is not a new phenomenon. Yet, the field of education lacks the theoretical and research bases necessary for the establishment of practice, guidelines, and protocol (Bonanno, 2010; Rieber, 2001; VanEck, 2007), with most research relying on inference from psychological and educational theory, rather than direct and sustained empirical evidence (Kirriemuir & McFarlane, 2004; Squire, 2002). The little research available primarily focuses on the development of specific competencies or literacies, though some proposed research models (Ecker, Müller, & Zylka, 2011; Kiili, 2007) and discipline guidelines have begun to surface (Bonanno, 2010; Kirriemuir & McFarlane; VanEck).

Threats to Effective Implementation of Education Games in Classrooms

Though games offer promising academic results, logistical issues hinder employing educational games in the classroom. Teachers are limited in the time and resources required to implement learning activities that engage students in authentic practices (Edelson & Reiser, 2006). A standards system does not currently exist to help teachers identify the degree of relevancy a game has towards components of a statutory curriculum. Teachers face difficulty assessing game content as appropriate, applicable, and accurate for classroom use. Further, if mechanics of game play supersede educational value, then the learning environment may be jeopardized instead of benefitted. Game- and instructional-design must be synthesized in research and development (R&D) processes. Further, the application of game-based learning has not been fully realized in learning environments due to a lack of empirical evidence supporting beneficial claims (Bonanno, 2010; McClarty et al., 2012). With insufficient emphasis on the context of game-based learning (Federation of American Scientists, 2006), the field needs a game that has undergone a rigorous R&D process from the beginning to the end.

Implementation of games entails satisfying technical, protocol, and curriculum issues. Technical requirements such as hardware and software requirements must be met for computer-based operations (Muwanga-Zake & Frank, 2010). Timing is a significant issue for implementing a game into a school curriculum. If connected to learning strategies, games will take longer. The untraditional length of time requires approval, planning, and negotiation with school staff and administration (Muwanga-Zake & Frank). Another hindrance of large-scale game-based learning realization in the classroom is having to persuade traditional administrators and school stakeholders of the inherent benefits (Kirriemuir & McFarlane, 2004)–an ambitious feat due to the prevalent dogma that gaming is just for fun and instructionally illegitimate (Bonanno, 2010; Rieber, 1996, 2001; Squire, 2002). The climate of traditional schools does not support the 21^{st} century learning that educational games foster, as "*the common teacher-centered classroom and typically overfilled curriculum obviate the entire suite of* 21^{st} *Century skills*" (Windschitl, 2009, p.5).

There is a discrepancy between what schools do and what research implies. In a longitudinal study from 1984 to 1991 exploring almost 70 research studies, Randel and colleagues (1992) concluded that for half the studies involved, educational games were found to be just as effective as traditional instruction approaches and even further, that such games were found to have a significant advantage over traditional instruction in about one-third of the cases. Despite research findings that have been around for over two decades, the use of educational games in schools has failed to be realized and is of increasing concern among the game research community (Kirriemuir & McFarlane,

2004) and those education researchers progressive enough to accept the potential of gaming by actually utilizing games (Ecker, Müller, & Zylka, 2011; Kafai, 2006; Kiili, 2007). Perhaps a driving force disconnecting research and practice is that play operates differently than how we have claimed it has (Sutton-Smith, 1995). Play is not a standardized test and thus cannot be caged or molded into such an artificial form. Imaginably, an alternative theory for humans and play that does not glorify prescribed skills to be attained (Sutton-Smith) may catalyze an educational transformation to function alongside culture instead of marginally on the outskirts.

Conclusions

Play is important because through it, we create (Sutton-Smith, 1995). Play taps into agency. Educational gaming induces the innovative 21st century learning (Edvardsen & Kulle, 2010) that values creativity. Though 21st century technology may help escort game-based learning into classrooms, a problem with our technological and information-based society:

> …is that we tend not to see that throughout history the adaptive advantage has often gone to those who ventured upon their possibility with cries of exultant commitment. What is adaptive about play, therefore, may not be the skills that happen to be a part of it, but the willful belief in one's own capacity for a future. (Sutton-Smith, p. 290)

Can we acknowledge game-based learning as worthy of study and use in its own right? Or, is its value only realized when coupled with digital technology or traditional assessment? To resurrect the play-factor of culture, perhaps we must consider elevating the status of play as a creative and agentic academic domain itself.

Acknowledging the philosophical, historical, epistemological, sociological, and cognitive foundations of play is important to understand educational gaming implications. Results from research studies in the later part of the 20th century depicted gaming as embedded in powerful social interactions (Tobin, 1998), with players often treating gaming environments as social gathering spaces (Greenfield, 1984, as cited in Kirriemuir & McFarlane, 2004). Because play has been regarded as an important mediator for socialization throughout life (Rieber, 1996), game designers who leverage notions of social learning, situated cognition, and social cognition may have a better chance of producing games with educational benefits.

Both commercial and educational games engage players in communities of practice, where player-participants share knowledge, skills, resources, symbol systems, and tools (Lave & Wenger, 1991; Wideman et al., 2007) to help one another accomplish the task at hand. Such collaborative play establishes a community sense of collective agency (Bandura, 2001). Interest is rapidly growing in employing social learning skills with games in educational contexts to foster collective problem-solving, to support social negotiations (Wideman et al.), and to encourage entry into a discourse community of learners (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Squire, 2002). After having participated in the Game Developers Conference and various science education conferences, I conclude industry and education domains have more to offer each other than what has been generally realized.

Though playing for learning has been around for millennia (Huizinga, 1938/1980), game-based learning has only entered the educational research literature in the mid-20th century, faced with resistance and limited acceptance. As the field of education has become more open-minded in general, the reluctance to acknowledge the potential of game-based learning has begun to diminish. More cases of game-based learning and instruction theory have entered the body of literature, though predominantly disconnected from one another, primarily digitally-situated, and for the most part disengaged from the game development community.

Education research has called for more empirical studies, for proposing guidelines and possible schemes to guide the field and game-design, and to integrate game-design with instruction-design. With a foundation of powerful theories and with a limited but growing body of evidence on the 21st century learning benefits of educational games, game-based learning appears to have a bright future. Perhaps through game-based learning, authentic play may usher in an empowering aspect to 21st century learning for personal, sociological, and cultural growth.

CHAPTER III

THE RESEARCH AND DEVELOPMENT OF AN EDUCATIONAL BOARD GAME FOR 21ST CENTURY STEM LEARNING

In response to the benefits associated with game-based learning (Ceangal & McFarlane, 2006; Oblinger, 2006; Wideman et al., 2007; Williamson & Sanford, 2011), researchers have called for the research and development (R&D) of games (Kiili 2007; VanEck, 2006; Ceangal & McFarlane, 2006; Rieber, 2001). Specifically, researchers have called for educational games to be created with respect to social learning theories (Rieber, 2001, 1996), such as constructivism (Kafai, 2006), and to be synthesized with game-design (Schwartz & Bayliss, 2011). Constructivism regards learning as a unique product that individual learners construct in combining new knowledge and experiences with existing knowledge and experiences (Dick, Carey, and Carey, 2001). In social learning, other learners influence knowledge and experiences. In my R&D research, I addressed the call to carry out an R&D process for an educational game with respect to social learning theories. In creating *Earthquake*, I aimed to also synthesize instruction- and game-design. I made *Earthquake* through an R&D process drawing from game-design, social learning and constructivism. The targeted learning environment for *Earthquake* was high school science, technology, engineering, and mathematics (STEM) classrooms and other relevant learning spaces not strictly bound to STEM domains.

Rationale

Games have been shown to be effective learning tools (Kebritchi & Hirumi, 2008; Van Eck, 2007). Researchers have shown that well-designed games provide opportunities for players to develop and practice important abilities (Prensky, 2001; Rossiter & Reeve, 2010; Squire, 2002), such as critical thinking, scientific argumentation, and metacognition (NRC, 2011, 2007a, 2000). Well-constructed educational games can also blend science and engineering design (see Schwartz & Bayliss, 2011), which is an important new perspective adopted by the *Next Generation Science Standards* (2013).

Within the safe realm of a playing space, students resolving cognitive disequilibrium can progress into the problem solving involved for scientific inquiry (Van Eck). Embedding play within a game constructed with respect to social learning may satisfy players' motivational needs (Deen & Schouten, 2011) to participate in their own learning (Rossiter & Reeve, 2010). Such games stimulate critical thinking, agency, and analytic engagement (Rossiter & Reeve). Playing quality educational games can cultivate 21st century science learning. Abilities of systems thinking, small-group complex communication, non-routine problem solving, generating questions, re-framing problems, and abstract thinking are culturally uncommon in American science classrooms (Windschitl, 2009). Thus, let us do something about it by incorporating quality games into learning environments.

Problem Statement

While the field of education has begun to accept game-based learning as a legitimate form of instruction, the field has not yet demonstrated how games link play and learning (Ecker, Müller, & Zylka, 2011; Van Eck, 2007). Some scholars claim this is because the literature lacks methodological validity or credibility (Wideman et al., 2007; Williamson & Sanford, 2011). Though researchers have emphasized the importance of blending instruction- and game-design (Charles & McAlister, 2004; de Jong & van Joolingen, 1998; Ecker, Müller, & Zylka ; Egengeldt-Nielsen, 2005; Garris, Ahlers, & Driskell, 2002; Kafai, 2001; Leemkuil, de Jong, de Hoog, & Christoph, 2003; Squire, 2004), few have actually synthesized the two (see Schwartz & Bayliss, 2011) in an applicable format for research or practice (Kebritchi & Hirumi, 2008; van Staalduinen, 2011). Further, many educational game developers have not reported research and development (R&D) processes for instruction- or game-design, let alone an R&D process synthesizing the two.

Purpose of the Study

As catalysts for learning, researchers have claimed that games (Oblinger, 2006) support the development of higher-order communication and thinking skills (Whitebread, 2001). By engaging players to learn-by-doing, games foster authentic knowledge constructions and offer opportunities for meaningful learning directed away from the fragmentation of inert bits of factual information. Though the educational potential of games warrants increased realization, games remain under-utilized in the classroom. In pursuit of bringing an instructionally sound game into the classroom, I chose to chronicle the R&D of an educational game about earthquake engineering.

I capitalized on the motivational essence of play to create an educational game, called *Earthquake.* The game provides players opportunities to practice and improve critical thinking, scientific argumentation, and metacognitive abilities as they construct content knowledge about engineering. Improving higher-order thinking and acquiring knowledge about engineering design are key aspects of 21st century science learning (NGSS, 2013). I created the earthquake engineering game in accordance with *Next Generation Science Standards* for a scientifically literate citizenry. *Earthquake* provides players in collaborative groups to learn from each other as they to do science, understand science, produce scientific knowledge and abilities, and to blend science with engineering design. The interdisciplinary content domain anchoring the game is earthquake engineering. The complexities, systems thinking, collaborative discourse, and real-life relevancy of the domain of earthquake engineers offers an appropriate context for game development.

Research Questions

For this case study, my goal was to generate an instructionally sound educational game anchored to earthquake engineering. My research questions were:

(1) What major steps will I need to modify in a typical R&D process to develop a prototype for an educational game?

(2) What major steps will I need to take to inform the original design of the game prototype and then pilot test the prototype?

(3) What steps will I take to make modifications and revise the prototype of the game before testing it with high school learners?

Conceptual Framework

I aligned a socio-cognitive conceptual framework (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Zimmerman, 1995) to the R&D of the game with instruction organized for the development of 21st century cognitive skills and for content knowledge acquisition. My conceptual framework for this study consisted of situated learning, social cognition, and socio-cognitive theory all focusing on learning-by-doing (Barron et al., 1998) within the context of collective agency (Bandura, 2001) through sharing, defending, reflection, and revision (NRC, 2007). Furthermore, I also delineated a framework for the critical terms of "play" and "game" and the phrase "game-based learning."

While a variety of definitions of the term "play" have been suggested, I aligned this study with conceptualizations proffered by Johan Huizinga. Others derived a philosophically grounded framework generalizable enough for salient compatibility with classroom learning from Huizinga (Schwartz & Bayliss, 2011). A play theorist, Huizinga outlined one of the first recorded play platforms (Huizinga, 1938/1980), that: entry into play is a voluntary act, unable to sustain suspension or deference; play transcends ordinary life into a mystic consciousness; play requires order, through which rules should not be broken lest one becomes a spoilsport; and that productive play is socially rooted.

The definition of a "game" reflected that of Csikszentmihalyi (1990) who has conceptualized that "games fill out the interludes of the cultural script" (p. 81). Games have offered players more freedom to learn from mistakes, errors, and failures (Gee, 2003; Veen & Staalduinen, 2009). A quasi-bounded and socially justified arena of arranged potentialities that produce interpretable outcomes (Malay, 2007), a game can be a medium through which play functions. "Game-based learning" has invited players to apply deeper levels of knowledge and skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956; Webb, 1997) while developing 21st century abilities (Galarneau & Zibit, 2011; Gee, 2009; Kirriemuir & McFarlane, 2004; Williamson & Sandford, 2011).

Methodology

In this qualitative case study, I chose to follow the instructional R&D process proposed by Dick, Carey, and Carey (2001), which consists of five phases: *Analyze*, *Develop*, *Design*, *Implement*, and *Evaluate*. The first four phases of the R&D process were the focus of this chapter of the dissertation. I used Chapter Four to provide results of the fifth phase, during which high school students played the *Earthquake* game. Functioning together as an instructional design, researchers have referred to these five phases as *Instructional Systems Development* (ISD), and they have associated them with contemporary views of instruction adopting socio-cognitive and situated cognitive theories (Dick, Carey, & Carey). Dick, Carey, and Carey developed their model as a general methodology for producing instruction. Both instructional novices and seasoned practitioners have applied the model to produce instruction. Iterative and nonlinear, the model has served as an appropriate template for inductive projects (Dick, 1996) such as the R&D approach for designing educational games.

Overview of R&D Strategy

Dick, Carey, and Carey (2001) have argued that an instructional model for designing classroom instruction should not determine the learning goal, but instead should allow for the designer to construct their own instructional goals by whatever relevant means are chosen. In the *Analyze* phase of the ISD model, a designer analyzes learners, contexts, instructional conditions, and writes performance objects. In the *Develop* phase, a designer develops relevant assessment instruments and instructional strategies to facilitate learners in meeting performance objectives. In the *Design* phase, a designer tests the developed instruction in an appropriate setting to gather both formative and summative feedback. In the *Implement* phase, the designer imputes necessary changes to their instruction based on the design feedback captured. In the *Evaluate* phase, the designer tests the finalized instructional product with learners in an appropriate setting.   For the context of the constructed earthquake engineering game, Table 3.1 outlines the data sources and analytic procedures for the four R&D phases addressed in this chapter.

Table 3.1

R&D Phases, Data Sources, Respondents, and Procedures for Analysis

R&D Phase	Research question	Respondent(s)	Data source(s)	Analysis procedures
1) Analyze	What literature currently exists to inform the development of a 21st century educational game centered on science learning?	Literature review	National science education reform documents; Instruction and game design references	Assess the state-of-state of play, learning, and game-based learning; write game performance objectives; determine game domain foundation
2) Develop	What major steps will be completed to develop the prototype for the game?	Experts (14) from varying backgrounds	Eight focus groups [video tapes, field notes]	Iterative game prototype development; balancing learning and game mechanic components
3) Design	How will the prototype of the game be designed and what steps will be taken to make an informed revision of the design?	Four groups of teachers (14) who played the prototype during a STEM professional development workshop	Interviews of the teacher game groups [audio tapes, field notes]	Constant comparison for emergent themes to improve the game [video tapes, field notes]
4) Implement	How will suggested modifications be addressed in the revision of the original prototype of the game?	Focus group (4) with researchers (3) who participated in constant comparison	Resulting teacher feedback from constant comparison	Verify and impute constant comparison results into the game modification

Throughout the R&D process, I prioritized the purposeful cohesion of instruction- and game-design. In that regard, I believe that this discussion of R&D phases would be not be complete without including techniques for synthesizing both instruction- and game-design.

Synthesis of Instruction and Game Design into R&D

I began the R&D framework for synthesizing instruction- and game-design with the instructional foundation of Dick, Carey, and Carey's (2001) ISD model. I superimposed both game- and instruction-design principles onto this foundation of an iterative nonlinear R&D process. Following game-design recommendations for game-based learning from Schwartz and Bayliss (2011), I replaced the word "learning" with "playing" in the ISD model. As synthesis appeared increasingly important through the game R&D, I found that the big themes of synthesizing instruction- and game-design distinctly emerged in two phases.

During the *Develop* phase in which the game prototype was constructed, focus group members represented backgrounds in science education research, science teaching, earthquake engineering, game design and gaming community membership. Including those with varying backgrounds has been identified as an essential skill for a game designer (Schell, 2015). I used Schell's game-design tips for productive prototyping in the *Develop* phase, thus establishing a game-design layer on an instructional foundation. For example, the building process began as a physical prototype which enabled problems to be spotted sooner than if it had been digitized.

During the *Design* phase, the teacher-participants were prototype testers. Teachers were the established prototyping priority; the game would be meaningless if the teachers–those delivering the game into the intended environments–found the game invaluable (Schell, 2015). The teachers provided feedback to improve the game. I integrated their feedback into the *Implement* phase. Including teachers' voices further imputed an instructional layer into the synthesis. Additionally, I iteratively used the game-design principle of needing to include no more than five and no less than three players per game to work out game-design issues (Moore, 2015). By targeting teachers as the prototype testers and bounding game groups to an empirically derived number (Moore; Nielsen, 2012), I established further instruction- and game-design synthesis.

R&D *Analyze* Phase: Analysis and Findings

What literature currently exists to inform the development of a 21st century educational game centered on STEM learning? Before creating instruction, an instructional need must first be determined (Dick, Carey, & Carey, 2001). Thus before game development could begin, I analyzed relevant literature first to review previous research, investigate any literature gaps, and provide a strong foundation for the study. As an extrapolation of Chapter Two in this dissertation, the literature review served as the *Analyze* phase with which I conducted instructional analysis, wrote performance objectives, and analyzed learners and contexts.

Limited and blurry, educational gaming perches on the boundary of the body of literature within education and gaming (Wideman et al., 2007), even though educational games support the development of critical thinking, problem solving (Whitebread, 2001), and metacognition (Kim, Park, & Baek, 2009). The popularity and potential of games is growing, despite traditional schools of thought stereotyping gaming as an invalid form of instruction (Rieber, 2001). The area of educational gaming and game-based learning is messy. The majority of studies in the literature are attached with digital game-based learning or electronic gaming (see Ecker, Müller, & Zylka, 2011), with an argument that, "The time has come to couple the ever increasing processing capabilities of computers with the advantages of play" (Rieber, 1996, p. 43).

Prevalent performance objectives in game-based learning research have been for players to acquire domain content knowledge. A negative stigma that games do not respect learning has hindered research in gaming, adding to the lack of cohesion among academic fields about what an educational game actually is and does. Definitions of instruction design–itself an interdisciplinary field (VanEck, 2007)–and learning vary throughout studies and time.

General conceptualizations of games include descriptors such as *immersive, social, motivational, simple, complex, boring, fun, serious, not serious, having clearly defined goals, well-defined problems, ill-defined problems,* and *designed with an intervention intentionally planned to solve a specified problem* or to simply *learn specific content*. Predominant game formats have included microworlds and simulations (Rieber, 1996), with the traditional board game fading in the background (Rossiter & Reeve, 2010). I have revealed in my literature review that the boundary conditions for an educational game and associations with learning theories have been ill-defined, interconnected, and often accompanied with negative images of gaming as an illegitimate form of instruction. As a result, I have found the web of instructional gaming to be tangled.

Social Learning and Gaming

Acknowledging the cultural contextualization of gaming has been important to understand educational implications. Researchers' results from studies in the later part of the 20th century have indicated that gaming is not just about playing a game, but is embedded in social interactions (Tobin, 1998). Players often treat gaming environments as social gathering spaces (Greenfield, 1984, as cited in Ceangal & McFarlane, 2006). Play has been regarded as an important mediator for socialization throughout life (Rieber, 1996). With this regard in mind, Rieber has contended that educational researchers who embrace a socio-cognitive approach can make significant contributions to a deeper understanding about the roles a well-constructed game can play in students' learning.

Both commercial and educational games can engage players in communities of practice (Lave & Wenger, 1991), where the players share knowledge, skills, resources, symbol systems, and tools (Wideman et al., 2007). Players help one another accomplish the task at hand, which establishes a community sense of collective agency (Bandura, 2001). Interest has been surging to use social learning skills with games in formal education contexts. Linking social learning and game-based learning can foster problem solving, support social negotiations (Wideman et al., 2007), and encourage entry into a discourse community of learners (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999).

Beginning in the latter half of the 20th century, powerful theories of learning emerged. Core notions of effective game-based learning included resonant themes such as reflection, authenticity, collaboration, learning-by-doing, flexible thinking, problem-solving skills, and decision making (Ceangal & McFarlane, 2006; Kiili, 2007). Progressive theories such as situated and social leaning (Brown, Collins, & Duguid, 1989), socio-cognition (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Zimmerman, 1995), anchored instruction, problem-based learning (Barron, 1998), and collective agency (Bandura, 2001) identified learning scenarios and environments to which games may be conducive in fostering (Rieber, 2001). Towards the end of the first decade of the 21st century, learning theorists and educators have increasingly acknowledged games as useful instructional tools and have associated play as an important venue for learning (Kinzie & Joseph, 2008), as education, psychology, and even anthropology research has qualified play as a powerful learning and social mediator (Rieber, 1996).

Games embody qualities of how people learn (Oblinger, 2006). By playing games, students learn how to think flexibly (Whitebread, 2001), collaboratively, and reflectively (Kiili, 2007), due to playing requirements such as recalling prior learning, constructing new knowledge, and decision making. Successfully implemented game-based learning employs basic principles of problem-based learning (VanEck, 2007):

contextuality, collaboration, and experientialism (Boud & Feletti, 1991). Gaming models, such as problem-based gaming, harness the authenticity of learning tasks, collaboration, and experiential learning (Kiili, 2007). Regarded as highly important in facilitating higher order-thinking skills, authentic learning situations anchor knowledge construction into meaningful real-life problem-solving scenarios (Brown, Collins, & Duguid, 1989).

Games embody such situated learning and cognition (VanEck, 2007). Contextualization and experientialism of situated learning theory (Brown, Collins, & Duguid, 1989) have been supportive of the ability to transfer new knowledge and skills into applicable practices (Savery & Duffy, 1995). Contextualized knowledge has been regarded by researchers as useful knowledge, since the learner develops a deep understanding of the interactions between knowledge and process, problem solving, and higher-level thinking (Bransford, Brown, & Cocking, 2000). Well-designed educational games offer flexible, collaborative, and reflective thinking, which have been regarded as important features in designing learning environments for meaningful learning (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999). Though instructional and social implications for educational gaming may appear somewhat connected, research circles have, in general, neglected the social contexts and the pedagogical possibilities of gaming (Bonanno, 2010).

The Literature Gap and Hindrances to Realization

Literature across domains and for ranges of age groups has inferred the effectiveness of game-based learning. For example, game-based learning has been associated with encouraging various cognitive and psychomotor skills (Dempsey, Rasmussen, & Lucassen, 1996), strengthening spelling and decoding performance in kindergarten students (Din & Calao, 2001), helping primary school students with poor reading skills (Schwarz, 1998), and increasing language proficiency in ESL middle-school students (Herselman, 1999); the list goes on. Yet, the theoretical and research base necessary for the establishment of practice, guidelines, and protocol (Rieber, 2001; VanEck, 2007) are lacking. Most research has relied on inference from psychological and educational theory rather than direct and sustained empirical evidence (Ceangal & McFarlane, 2006). The little research available on the efficacy of game-based learning primarily focuses on the development of specific competencies or literacies. While some proposed research models (Kiili, 2007) and discipline guidelines have begun to surface (Ceangal & McFarlane, 2006; VanEck, 2007), game-based learning and play for learning merit further exploration.

Though games pose promising academic results, logistical issues have hindered employing educational games in the classroom. A standards system has not existed to help teachers feasibly identify the degree of relevancy a game has towards components of a systematic curriculum. Teachers face difficulty is assessing game content appropriateness, applicability, and accuracy for current practical classroom use. For example, U.S. schools do not, in general, provide enough support for teachers to engage in longitudinal professional development. Due to bureaucracy, politics, low pay, and low social appreciation (Darling-Hammond, 2010), teachers face challenges finding time to familiarize themselves with game content as well as with methods conducive to effective utilization (Ceangal & McFarlane, 2006).

Research circles should collaborate to provide evidence to traditional administrators and school stakeholders of the inherent benefits of gaming (Ceangal & McFarlane, 2006). A prevalent dogma in traditional schools has been that gaming is just for fun and instructionally invalid for meeting curriculum or performance standards (Rieber, 1996, 2001). Research circles, teachers, administrators, and school stakeholders must collaborate to overcome destructive stigmas.

A long-term gap has existed between what schools have been doing and what researchers have been implying. In a longitudinal study from 1984 to 1991 of almost 70 research studies, Randel and colleagues (1992) concluded that for half the studies involved, educational games were found to be just as effective as traditional instruction. Further, the games studied were found to have a significant advantage over traditional instruction in about one-third of researched cases. Educational games work and can be more powerful than traditional instruction. Despite these research findings, school leaders have not sufficiently employed educational games in schools; they have not recognized the potential of games as significant learning tools. The potential of educational games not having been realized by educators in the field has been of increasing concern among the game-based learning community (Ceangal & McFarlane, 2006).

Summary of R&D *Analyze* Phase

Use of theory in educational gaming has been lacking, specifically with respect to constructivism and social learning. Contextualizing learning in authenticity has shown to enhance the environment, providing learners with autonomy and a community-sense of belonging. Games have done this (Rossiter & Reeve, 2010). The lack of research on the instructional validity of games perhaps has contributed to the resistance to classroom implementation of educational games. In this regard, I outlined the performance objectives for *Earthquake* to teach players critical thinking, scientific argumentation, and metacognitive abilities. Additionally, I outlined the knowledge interdisciplinary content performance objective to introduce earthquake engineering through a socio-cognitive constructivist lens. I navigated game construction through this perspective to allow players to personally construct their own knowledge frameworks in an environment driven by the motivation of play in a community of learners. Fundamentally, I identified the performance objective of the game as to engage players in 21st century science learning. The 21st century performance objectives were for players to practice and improve abilities in critical thinking, metacognition, and scientific argumentation, which have been considered as pivotal to effective 21st century learning (Sabaurin & Lester, 2014).

R&D *Develop* Phase: Analysis and Findings

What major steps will be completed to develop the prototype for the game? In the *Develop* phase, I used information from the *Analyze* phase to create a method for providing instruction to learners (Dick, Carey, and Carey, 2001). I held focus groups to provide an instructional method with respect to social learning and constructivism to develop a gaming framework with functioning logistics. Serving as assessment instruments themselves, the focus groups developed and selected the instructional materials and general schematic of the game.

In eight meetings spanning five months, the focus group members (n=14) guided basic construction processes, tested strategies, and fine-tuned game mechanics. The video-recorded meetings lasted from two to six hours. Experts from various backgrounds comprised the focus groups: science education researchers, science education post-doctoral students, science education doctoral students, civil engineering post-doctoral students, and individuals involved in a gaming community. The civil engineers participation in the form of a focus group occurred during the *Design* R&D phase, which allowed for more salient communication of engineering content knowledge recommendations (See R&D *Design* Phase: Analysis and Findings). Though I was the lead game designer, I reference myself as a science education expert in the focus group descriptions below. I facilitated the focus groups, communicating throughout the *Develop* phase that the incentive of the meetings were to draft an engaging product to hook players, allowing them to become immersed in the context of the game and to learn-by-doing.

Focus Group 1

The first, longest, and largest focus group contained two science educators and four gaming experts. The goal of this first meeting was to develop a game reflecting the earthquake engineering themes in Figure 3.1. I projected this diagram in the room for the entirety of Focus Group 1, referring to it often.

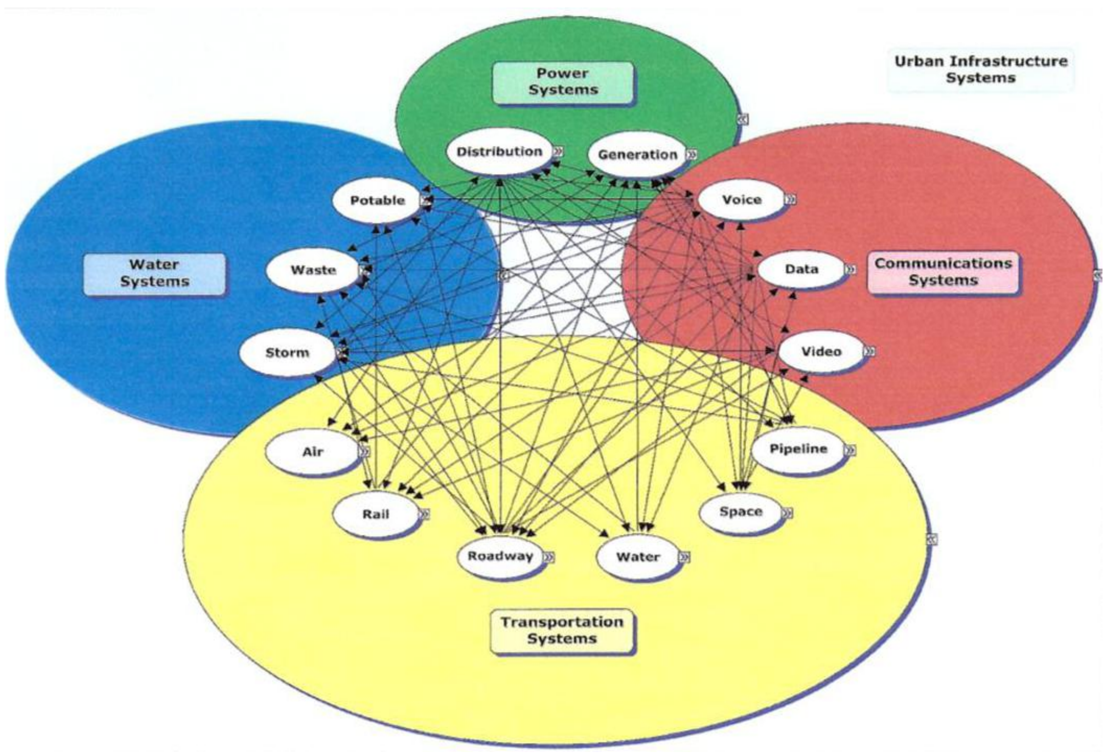

Figure 3.1. Diagram of urban infrastructure systems projected in the room during Focus Group 1 (Fry, 2012).

This diagram depicted the interconnectivity of the four main components to urban infrastructure (Fry, 2012): water, power, communication, and transportation. The focus group brainstormed to establish an initial board set-up, which consisted of hexagons enclosed in a rectangular space. We considered different ways to fashion a fault line for representing the most dangerous areas in the event of an earthquake.

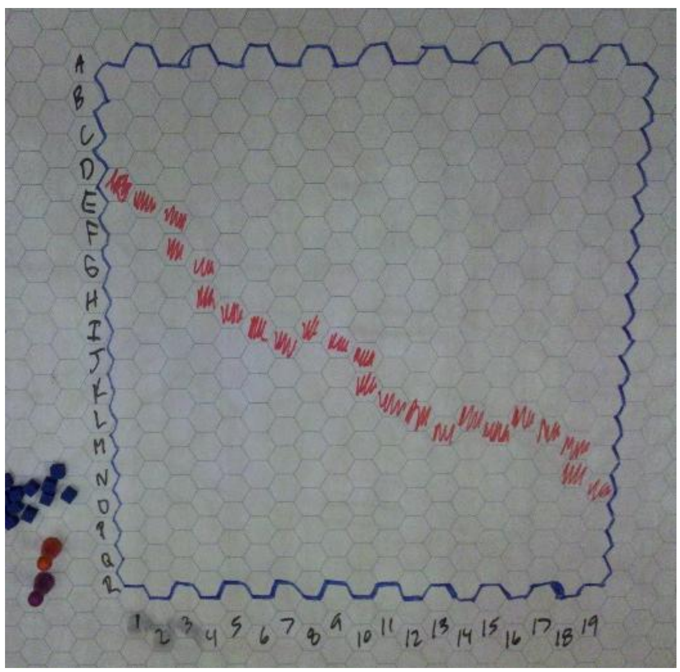

Figure 3.2. Example board template developed during Focus Group 1.

Focus Group 1 identified the need for physical game pieces to correspond to each of the four main components of urban infrastructure: water, transportation, communication, and power. We debated the roles of cards, as well as how many decks would potentially be applicable. The group quickly dismissed the idea of a spinner to identify earthquake damage levels. We replaced the spinner game-mechanic with a six-sided die to elucidate the notion of the unpredictability of earthquakes in real life with current technology.

Focus Group 2

Comprised of two science educators and one gaming expert, Focus Group 2 categorized the physical game pieces into resources, hubs, and decks of cards. Small wooden blocks represented urban infrastructure resources. The blocks were black, blue, red, and yellow to symbolize the four main components of urban infrastructure. A blue block represented a water resource; black block represented a transportation resource; red block represented a communication resource; and a yellow block represented a power resource. These physical blocks embodied the urban infrastructure components as resources to use to build hubs within a sector. A rule was created that the first resource block in any sector must be a water block, as water has been regarded as the most important component of urban infrastructure (Fry, 2013).

Focus Group 2 designed the sector layout of the board. The red sectors in the middle of the board corresponded to the earthquake epicenter, with orange and yellow sectors occurring further away. See the rulebook in Appendix A for pictures and a more detailed description of a sector. Seven hexagons comprised a sector. The outer six hexagons were spaces where resources could be placed. When a specified combination of resources had been placed in a given sector, a hub piece could then be placed in that sector's middle hexagon. At this stage, the hubs represented basic city buildings, such as a post-office or city hall.

During Focus Group 2, we played with only one deck of cards in the hopes of minimizing physical components. This deck consisted of resource cards, event cards, and hub cards.

Figure 3.3. Focus Group 2 with cards.

Every turn, a player drew two cards and took two moves. For example, if a player drew a water resource card, the player could take a blue resource block and place it in a sector with the aim of building a hub or adding redundancy and resilience to a sector. At this point in the development process, we had not yet established a win condition. The game was still in an abstract phase of creation, as rules were made, broken, and taken away throughout the meeting.

At the end of the Focus Group 2 meeting, we had developed a functioning concept for the game using resource pieces to build hubs. The collaborative nature of the game had become apparent. At this juncture, we decided that the players needed to build on each other's plays and work together as a city council team. The group also proposed the idea of introducing two or more decks of cards.

Focus Group 3

Focus Group 3 consisted of three education experts, two of whom were new focus group members. In Focus Group 3, we tested two decks of cards, a resource deck and an event deck. The resource deck simply contained cards for each of the four resources. The event deck drove game play with both positive and negative occurrences, such as earthquakes. These cards required players to remove resources from the board and granted extra resources to be played.

Figure 3.4. Focus Group 3 balancing event card logistics.

At this point, we had not conceptualized the role of each hub. We simply accepted the need as a representation of a form of infrastructure that helped the city prepare for and/or recover from an earthquake. We realized that event cards were conceptually sporadic and needed honing. In Focus Group 3, we diagnosed a boundary condition within which the event cards were to function. The event cards had to stay within the playability of the resource pieces. In other words, responses to drawn event cards were to be carried out using resources on the board or resource cards held by other players.

Focus Group 4

Focus Group 4 consisted of two science educators and one gaming expert. In Focus Group 4, we introduced the function of the hub cards. We decided that hub cards would have a separate deck, instead of being mixed in with the event cards. The hub deck would consist consisted of the different types of hubs that could be built on the board. At this time, we also implemented a standard turn sequence of player turns. At each turn, a player first would draw one card off the event deck, then could either draw one card from the resource deck or select a hub card to take. Then a player could take two actions, where an action consisted of playing one resource piece on the board. During Focus Group 4, hubs were represented on the board by random office supply pieces small enough to fit in the middle hexagons of the sectors and were named hub tokens.

We also decided that playing a hub token on the board would constitute an action and that hub tokens would only be played on a given sector if the required resources for that hub had already been placed in that sector. During Focus Group 4, the complexity of the rules became noticeable, though necessary. We made recommendations to Focus Group 5 to help Focus Group 5 manage the complexity of the game space and the rules. We also recommended to Focus Group 5 the need to integrate a salient win condition.

Focus Group Five

Focus Group 5 consisted of one gaming expert and three science educators, one of whom was a new focus group member. One of the most instrumental groups, Focus Group 5 collapsed the basic game-design mechanics into functional instruction. Of critical importance to tie game- and instruction-design, we set the win condition to be the game-group that would accumulate the most people points. The game at this point integrated concepts of civil engineering through building hubs with resources. We had established that the water resource had to be the first resource placed in any sector. However, the most important element of engineering was missing: the human element (Stuessy, 2013). Why build a city if there are no residents or members to participate in the city?

Figure 3.5. Focus Group 5 establishing the win condition.

Thus, we introduced a second type of hub to accumulate people points, a residential hub. The previously designed non-residential hubs were designated as urban infrastructure hubs and categorized as either a water hub, transportation hub, communications hub, or power hub. The game guide in Appendix B lists all the hubs from which players would choose to build.

Introducing the residential hub allowed for a functional win condition. Built residential hubs gave people points, an abstract quantitative measure of a city's habitability before and after an earthquake. Residential hubs also personalized play. This hub represented a city's ability to provide disaster response to people inhabiting the city, such as supplying residents with temporary housing facilities, food and clean water, communication to neighboring cities, and basic and emergency medical care. The residential hub also served as a point of contact for disaster relief organizations, such as the Red Cross.

As the game was being developed to be collaborative within a group of players, we decided to also add a competitive component between different groups playing their own games at the same time. The competitive factor was incorporated as a motivational driving force, often used in game production to help players enter and remain in a flow-state (Schell, 2015). This decision, however, meant that teachers would require multiple copies of the game in a classroom. Multiple games would permit groups to collaborate within each game-group and also to be motivated by the competition to win between groups. We determined in Focus Group 5 that game-play would be about an hour and a half–the time interval for most schools adopting the block schedule of longer class periods. The group with the most people points, as determined by the number of functioning residential hubs on the board, would win at the end of the game.

Focus Group 6

Focus Group 6 consisted of one gaming expert and three science educators, one of whom was a new member. In Focus Group 6, we experimented with event card balance. From an instruction (Stuessy, 2013) and game-design perspective (Schell, 2015), the event cards would have to be challenging in a way that was neither overwhelming (i.e., inciting frustration) nor underwhelming (i.e., causing boredom). With the types of event cards primarily set from previous sessions, we specifically tested the game with varying numbers of earthquake cards in the event deck. We determined in Focus Group 6 that six earthquake cards in the deck of about 90 event cards was an appropriate amount to instructionally convey to players the need for planning and managing earthquake damage. We decided that this proportion would lead to a challenging but not overly frustrating game situation. The group established the priority that the game players should be challenged to build an inhabitable and earthquake-resilient city. That is, we accepted there would be times when players could become discouraged by the drastic amount of damage their city would undergo in the event of an earthquake. Focus Group 6 affirmed that the level of earthquake damage was to be determined by the number rolled on a six-sided die by the player who drew an earthquake event card.

We paid close attention in Focus Group 6 to balancing events and resources so that players would be motivated past discouragement by the drive to meet the operational game goal of building a city capable of managing earthquake damage. To help players begin their game, we decided in Focus Group 6 to include a city hall section on the board where four resource cards would be placed at the beginning of the game for any player to use as an action. These beginning resources served as a kick-start to get the game rolling, supplemental to the standard draws each player could take during a turn sequence. Focus Group 6 also determined to include this city hall concept as a hub that players could build on the board to continue the city hall function if they, as a group, choose the city hall over other hub options. We recommended in Focus Group 6 that small, circular, plastic, colored tokens would replace the wooden blocks as the resource pieces, arguing that such flat tokens would be more maneuverable than blocks.

Focus Group 7

Focus Group 7 consisted of four educators, two of whom were new focus group members. Preserving the color scheme, plastic resource tokens replaced the wooden blocks, with additional purple tokens representing hubs. In Focus Group 7, we recommended putting pictures on the purple hub tokens to symbolize specific hubs. We intended for the pictures to correspond with the pictures on each respective hub card, helping players to easily relate a hub picture to a hub function as specified on a hub card.

In Focus Group 7, we solidified the center sector of the playing space, called main hub, to be the location where game-play begins. We decided that the middle hexagon of the main hub sector was to be blue to indicate that this was the city's water source, which is why the city would begin here. A city must have water to survive (Fry, 2013).

We confirmed zone areas on the board to consist of sectors according to distance from the middle of the board. Zones were confirmed as red, orange, and yellow groups of sectors. The red zone was at the earthquake epicenter, with the less danger orange zone neighboring, and the even lesser dangerous yellow zone neighboring the orange sectors within the orange zone. During some test-plays, this danger sequence was reversed with the outer sectors being the red zones where play would begin. We determined this to be too easy to expand from the innermost hub (i.e., main hub) and was thought to make the realism of the game less transparent.

Focus Group 7 implemented the rule that to expand out from any sector, that sector must contain at least one of the four main urban infrastructure components (e.g., a water resource token, a transportation token, a communications token, and a power token). We intended for this rule to help elucidate to players through repetition the essential interconnectivity of the four main urban infrastructure components. We also discussed in Focus Group 7 the idea of giving players identifying roles to help players manage the complexity of the game.

Focus Group 8

Focus Group 8 consisted of four science educators. Following the previous session's recommendation of establishing a system of player roles, we tested a mayor role in Focus Group 8. The mayor maintained resource management at the end of each round. We organized a mayoral checklist (See Appendix C) to aid the mayor in remembering what to do. Additionally, we each played with a game guide (See Appendix B) to test for helpfulness of the game guide in playing the game. The game guide listed all the hubs, the resource requirements for each hub, hub upgrade requirements, including the residential hub and associated number of people points. The game guides also included the turn sequence, basic rules to remember, and an earthquake checklist of what to do when an earthquake card has been drawn from the event deck.

We Focus Group 8 members agreed that the mayor role, the mayoral checklist, and the game guide were immensely helpful in facilitating game-play. Prior to using the game guide, for example, we as players had to sort through the hub card deck as part of the decision-making process of what hubs we would choose to build. The game guide consolidated this information, as well as basic game logistics, onto one sheet of color-coded paper.

Summary of R&D *Develop* Phase: Prototype Synopsis

Focus groups used a socio-cognitive conceptual framework (Goldman, Petrosino, & CTGV, 1999; Zimmerman, 1995) to align the development of *Earthquake* with instruction organized for the development of critical thinking, scientific argumentation, and metacognitive abilities around earthquake engineering content knowledge. As students' prior knowledge had been regarded to critically affect learning (NRC, 2007), I aimed for the game to employ prior knowledge to enhance the social learning environment. I integrated scientific inquiry features of synthesizing, planning, and decision-making (Blumenfeld, Kempler, & Krajcik, 2006) into the game-play features, figuring that learners must be engaged in these 21st century learning abilities to play the game. I concluded that players must be engaged in these features through game mechanics and learning theories in order to make their thinking visible using the physical constructs of the game board. With guidance from the other focus group members, I developed the prototype for the playing and learning to coexist.

Devised for three to six players per board with several games set-up in a classroom, the board consisted of sectors on which hubs would be built by playing resource tokens. Each game group would work collaboratively together, competing against other groups engaged in playing their own games. The group schema was constructed to function as a pedagogical tool within the context of the game mechanics; such a method has been proposed to use a gaming group as a pedagogical tool to improve collaboration and cooperation through group discussions and debriefing (Leemkuil, 2006).

Focus groups decided that the shared objective of all game groups was to build an inhabitable and resilient city in earthquake-prone areas of the world. After about an hour and a half, the group with the most people points would win. The educational goal with respect to content knowledge was defined to introduce civil engineering design and to teach the interconnectivity of main urban infrastructure components: water, transportation, communication, and power (Fry, 2013; Llinas, 2002). I defined broader goals to provide opportunities for the development and practice of the specific 21st century abilities of critical thinking, scientific argumentation, and metacognition.

From the focus groups, we had developed a functioning prototype with respect to socio-constructivist instruction and game design. In concluding the *Develop* phase, members of each focus group agreed the game was ready for a real test-playing scenario. Focus group members had expressed the need for teachers to test-play the game before students would test-play to gain basic insight on classroom management. An additional recommendation was to have earthquake engineers play the game as a check for correct domain content knowledge and terminology usage.

R&D *Design* Phase: Analysis and Findings

How will the prototype of the game be designed and what steps will be taken to make an informed revision of the design? With the instructional strategies and materials developed in the previous R&D *Develop* phase, the next R&D phase allowed me to design the formative assessment of the instruction (Dick, Carey, & Carey, 2001), or in the terms of this study, to design the formative assessment of the game. Workshop designers included the completed game prototype as an activity in a science, technology, engineering and mathematics (STEM) teacher workshop in the summer of 2012. The week-long workshop for middle and high school teachers was funded by the Earthquake Engineering Project (EEEP) through the National Science Foundation (NSF).

I used two sources of data for the R&D *Design* phase. The first was the teacher-participants from the workshop. The second was from test-playing the game with earthquake engineering post-doctoral students. Like myself, these two engineers helped coordinate the workshop at various points in time. In the *Design* phase, I described results of first teacher data from audio-taped interviews of fourteen teachers after playing the game in four groups for a period of about an hour and a half. After describing teacher results, I summarized input from the engineering students who test-played *Earthquake* with me. The test-pay lasted about an hour and a half, also.

Design **Guided by Teacher Interviews**

Participants of *Design* phase. Fourteen teachers from across the U.S. played in four groups on the first day of the week-long workshop. The teachers had already been recruited to participate in the workshop. The teachers were provided with the opportunity to volunteer in this research by playing the *Earthquake* game and then participating in group interviews, in accordance with the university's Internal Review Board (IRB) protocol. I communicated to the teachers verbally and in writing on consent forms that participation was voluntary and consent would not affect any relations with the workshop. All teachers volunteered and signed IRB-approved consent forms.

Data collection and analysis of *Design* phase. The teachers played in groups of four. Game play was proctored by a focus group member; each proctor also had served as that group's interviewer. After playing the game, each group was interviewed for thirty minutes to capture their playing experiences. Each group was audio-recorded.

Five open-ended questions guided the discussions: *What did you learn about earthquake engineering from playing the game? What did you like about the game? What did you dislike about the game? What would you change about the game? How effective is the game at teaching the interconnectivity of urban infrastructure components?*

I transcribed the four group interviews and analyzed them using constant comparative methodology for naturalistic inquiry (Erlandson, Harris, Skipper, & Allen, 1993) with the goal of uncovering pervasive ideas that best captured the game's essence and that indicated a need for modifications. I organized the transcriptions into thought segments. I coded and constantly compared on physical paper to reveal emergent categories subsuming specific modifications suggested by workshop teachers. Preliminary analysis resulted in four main emergent themes: educational value, game logistics, playing experience, and classroom orchestration. For organization purposes, I labeled each thought segment with identifiers for the group, person speaking, question of topic, and transcription page number. I consulted science education researchers throughout the process to aid in minimizing potential bias and unforeseen threats to reliability.

The final stage of teacher interview analysis entailed triangulation in the form of negotiating final qualitative results (Erlandson, Harris, Skipper, & Allen, 1993). The triangulation consisted of three people, including myself. A science education researcher who had served as an interviewer in the *Design* phase and as a focus group member in the *Develop* phase participated in this qualitative analysis. A science education graduate student unfamiliar with the game also participated. The three of us all met four times for several hours each. I video-recorded the meetings to reference as I progressed through the constant comparison. Purposefully sought out to employ the method of triangulation, these three unique perspectives aided me in establishing credibility within and among the themes, categories, and sub-categories derived from my analysis (Erlandson, Harris, Skipper, & Allen).

We met with the goal of providing guidance for modification of the game for high school students to play during the fifth R&D phase (i.e., the *Evaluate* phase). The purpose of this qualitative analysis was to capture general feedback to make physical improvements to the game. As a result, I did not seek a quantitative number, such as a percentage of reliability. Without knowledge of my coding system, however, the two others within the group developed their own coding system separately. Over the course of a month, we confidently agreed upon a final set of themes, categories, and sub-categories. I collapsed the original four themes into three, as illustrated be in Figure 3.6.

CLASSROOM ORCHESTRATION	EDUCATIONAL VALUE	GAME LOGISTICS
Operative Synchronization Monitoring Tangibility Transitioning Initialization **Social Dynamics** Competition Group-Work **Learning Progressions** Post-Game Discussions Locations Teachable Moments **Time Management** Time Requirements Scheduling	**Spectrum of Domains** Mathematics Science History Engineering **Metacognition** Argumentation Decision-Making **Potential** Positive Negative **Urban Infrastructure** Components Interconnectivity Resource-management: Building Damage mitigation Expansion **Cooperation** **Realism** Connections Accuracy Humanity	**Appearance** Positive Negative **Event Cards** Clarity Functionality **Hub Tokens and Cards** Clarity Functionality **Zone Areas** **Player Roles** **Infrastructure Management** **Getting Started**

Figure 3.6. Final themes, categories, and subcategories of teacher interview constant comparison.

During the final meeting, we were in agreement about the placing of each thought segment. We were confident in the function and exclusivity of the naming and purposes of the themes, categories, and sub-categories.

Results of teacher interviews. With the purpose of identifying teachers' recommendations for game modification, I focused analysis on how to best prepare the game for the next round of research. The other information the teachers provided could be addressed in a later study. The rich information the teachers supplied extends into analysis significant to other applications, such as how a teacher might manage game-play in a classroom, how the game strategically functions, and associated potential learning opportunities across various domains.

In general, the teachers supported the game as several requested copies to use in their own classrooms, indicative of the instructional credibility of the game. Informed by general positive feedback, I proceeded with the study under the impression the game would be realizable in a classroom setting and that further education research may ensue. Examples of positive feedback included the thought segments, "I liked it a lot," "It's pretty good. I really like it. I really enjoyed it," "Overall, it's a great game," "This is a really good game," "I love the strategy in the game," "It worked well. It flowed well," "Overall, it's just a good activity," "Yea, this was fun. I had fun," and "I'm not a game person, but I did enjoy it." The interview analysis provided me with sufficient information to implement several specific modifications: (1) the addition of distinct player roles, (2) clarifying phrases on event cards, and (3) producing an introductory video.

Addition of player roles. In the R&D *Develop* phase focus groups, the idea floated around about having a specific player role or player identity for each person playing the game. In an attempt to minimize the already exhaustive rulebook, the focus groups had decided to only include the mayor as a role in the game. Teachers suggested that such a role would be beneficial because, "…kids love [the] mayor [role]," and, "Yea, the mayor wasn't a bad idea." But, the teachers proposed the addition of player roles to, "make it [the game] more of a real-life experience for the kids." For example, one of the more experienced teachers of the workshop shared, "I think it's going to be necessary to have more duties, not just the mayor." Another teacher from a different game group further explained, "…you could [have] different positions. So, because sometimes if it's the mayor, the other students will think, 'Oh, it's your responsibility.'"

Recommendations to modify the game included, "It would be a good idea if there was an earthquake manager, kind of leading them through each sector." Another teacher from the same group as the previous commenter followed with, "That's actually not a bad idea–the earthquake manager. Because, that would be the voice we're talking about in terms of, you know…remember to be careful in case of an earthquake." This last comment was in regard to building hubs to prepare for and to mitigate earthquake damage, instead of trying to build as many residential hubs as possible in an attempt to gain people points and to win the game.

To address the teacher recommendations of player roles, I added two more roles. In addition to the mayor role that I drafted in the *Develop* phase, I added player roles to be the earthquake manager and the architect. From the teacher feedback within the *Design* phase, adding two more roles was deemed necessary for game flow. The earthquake manager was analogous to a city manager in real life, and would handle the actual disaster by communicating to the group how many resource tokens must be removed from each sector after an earthquake event. The architect's job description was to record what specific resource tokens and hubs would have been in each sector and keep records of which hubs built on the board would be functional (See Appendix A for detailed descriptions of how to play the game). I created record sheets that were scaled-down replicas of the board game. I intended for the mayor, earthquake manager, and architect roles to scaffold players to navigate building and maintaining an inhabitable and earthquake resilient city. Appendix C catalogs blank architect and earthquake manager sheets, along with examples I created to illustrate how players could use the sheets.

Clarification of phrases on event cards. The issue of clarification and functionality on what specific event cards meant came up in each teacher game group during the *Design* phase. For example, teachers expressed confusion on whether the bank loan card required an action to play and if the event cards pertaining to hubs not present on the board were applicable. All event card clarification comments were from two teachers of the same group and made comments such as, "Some of the [event] cards we were getting, we never got close to using them," and "We had like four earthquakes and they [in reference to another group] had like one." In reviewing the video-recorded game play of this group, it is unclear whether or not the game proctor shuffled the event deck of cards prior to game play, which would have limited the players' options of event cards to be drawn.

An experienced teacher from this group expressed, "…and that's what's really hard to do. As you're creating this [the game], it's just totally clear to you what you meant. I can read it, and the next person reads it and, 'What in the world were you trying to say with this?'" and "We had to get clarification from you [the proctor]. Especially with that fire [station hub]. Does that happen on this turn? The ones [event cards] that are not applicable unless you have that card, and then some of them are not." These comments were suggestive that, in general, the phrasing on the event cards needed to be changed to more clearly articulate the function of each card, regardless of whether the event card deck was adequately shuffled prior to game play. To address these issues, I fine-tuned each event card and cross-checked the modifications with a science education researcher.

Introductory video. Due to the complicated nature of the game–both an asset and a liability–teachers expressed difficulty in getting started and in understanding the rules enough at the beginning to get the game going. Though the complexity of the game was in general referenced as a quality that could hook students, the complexity of the game could also potentially deter students. To help players learn the basic rules of the game at the beginning, teachers recommended showing a short video to students, "like a three minute YouTube video of people playing and they're talking through it as they do it." One teacher suggested to treat the first time playing the game in the classroom like a lab, "We're doing it [a first lab] to get comfortable with the procedure and process before we turn you lose…they can take it slow, we can go back and revisit things we're doing." Several teachers recommended for the students to just, "sit down and play it," so students can be "doing it, especially with the kids. They want something in their hands that they can do." Teachers warned that, "just teaching them [students] the basics would be almost a class period." One teacher newer to the field said, "I would suggest not to present all the information before too much time ahead of the game…because that could be a little bit overwhelming."

Presenting all the information in the rulebook (see Appendix A) to students prior to game play would most likely be overwhelming. In combining several of the teacher recommendations, I scripted and produced a brief introductory video to provide new players a basic overview of how the game could work prior to game play. Each player would be provided a rulebook and could access information therein when needed. In the classroom setting, teachers would be encouraged to treat the first game-play similarly to a first lab, as students could familiarize themselves as individual players and as members of a playing community in the context of the game.

Design **Guided by Test Play with Engineers**

Two civil engineers and I played *Earthquake* during the middle of the workshop week. This was the same STEM teacher professional development workshop from which the teachers participated in the *Design* phase. Teacher data was derived from interviews. Whereas here, I collected data from my experience and field notes from test playing *Earthquake* with content experts. The post-doctoral civil engineers also served as domain resources for the participants during the STEM teacher workshop, in addition to providing game feedback to me. This test-play was supervised by my advisor in science education and the advisor of the engineers. Our advisors also headed the workshop.

The two engineers' participation aided in the instructional design of the game primarily for two reasons. Both brought an expert perspective of the civil engineering background to the table and also approached the game as first-time players. Prior to game-play, I specifically asked the engineers to critique phrases on game cards to more appropriately reflect basic earthquake engineering terminology and conceptualizations in all facets of game play. I encouraged them to share feedback throughout game, specifically regarding how to better contextualize the interconnectivity of urban infrastructure components while sustaining elements of realism without unnecessarily increasing complexity in game logistics.

Similar to the teacher participants' game-play, the engineers progressed through about two rounds of playing the game before expressing increased comfort in navigating through game turns and rounds. The following summarizes key issues the engineers addressed and the resulting modifications I carried out. Key issues identified were terminology usage, event card phrasing, and an additional game piece component.

Engineering terminology and content knowledge check. I had included in the game that a hub could be upgraded if players choose. The hub cards had an upgrade option, some of which were a "structural reinforcement" upgrade for the more conceptually tangible elements. I questioned whether the term "retrofit" would more appropriately articulate the upgrade scenario. Though using both terms would be considered acceptable, the term “reinforcement” was suggested as a better choice due to the generic nature of the concept. The engineers explained that “retrofitting” was a more substantial task that modifies equipment in designed systems that is made available after the time of original manufacture. “Reinforcing” was a smaller-scaled task that strengthens with additional support or material. Using the term “reinforcement” was suggested to allow the game to address the importance of sound structural engineering without having to go into too much construction detail that could potentially introduce unnecessary abstraction into the game-based learning.

Clarification of phrasing on event cards. The bank loan event card presented confusion as to whether or not procedures associated with the card counted as one of the two actions a player could take each turn. The bank loan allowed a player to borrow resource tokens from an arbitrary bank to be paid back later. Though the card included the phrase, “Does not count as an action,” this may have been too much detail, confusing players instead of helping. The purpose of the card had been for players to access needed resources, not to take away valuable actions. The bank loan event card did not require an action to borrow resource tokens. Paying the loan back also did not count as an action. To maintain consistency throughout all event cards, I decided to change only event cards that required an action. I rewrote the applicable event cards to specifically explain on the cards requiring an action to play that playing the card meant an action must be taken. Otherwise, an event card defaulted to not requiring an action to use.

The engineers encouraged me to deconstruct the descriptions on the event cards to contain minimal explanations, with the exception of one recommendation. If an event card pertained only to a specific hub on the board, then these event cards should first explain whether or not the event card was applicable. For example, if the fire station maintenance event card was drawn, the first two sentences on this card were suggested to read, “If the Fire Station hub is not on the board, discard this card. If the Fire Station hub is on the board, remove one water token to pay for building maintenance.” Originally, the rulebook noted that an event card was only applicable if the hub named on the event card was on the board. The engineers and the teachers occasionally overlooked this rule. Thus, I clarified phrases in the above fashion to accommodate this issue.

Addition of a player role. The engineers noted the complexity in the game associated with an earthquake, that is, when an earthquake card was drawn from the event deck. In the event of an earthquake, the game immediately halted while the players assessed how much damage our city had undergone, represented by how many resource tokens needed to be removed from each sector. Though I composed an “earthquake checklist” located on the game guide to direct players through earthquake response and recovery, the many different calculations required for each sector could have been too overwhelming for players. The engineers suggested adding a notional device to systematically simplify the assessment of earthquake damage.

Following feedback from the content knowledge experts, I implemented a unique role that one player would be assigned the responsibility of the earthquake manager. This recommendation was corroborated by the teachers who played the game during the workshop. I created a scaled-down replica of the board layout (See Appendix C). Whenever a hub would be added or upgraded, the earthquake manager would record any mitigating effects by writing the appropriate number to be subtracted from the determined earthquake damage level for each sector (See example earthquake manager record sheet in Appendix C). Once different hubs would be built on the board, each with a unique function and type of upgrade, the role of the earthquake manager could have allowed players to sort through the earthquake disaster systematically with less chance for arithmetic errors.

Managing non-functional hubs. After an earthquake, a hub may be non-functional if at least one of that hub's required resource tokens has been removed (See rulebook in Appendix A). With some hubs functional and others non-functional, remembering which hubs still work was cautioned as an unnecessarily remedial task. Accordingly, I introduced physical pieces as new game components. Composed of a flag pinned to a small base, the new pieces served the purpose of reminding players which hubs were non-functional. When a hub became non-functional, the architect would have placed a flag piece on top of each non-functional hub token. This visual layout could have allowed players to more efficiently progress through the game by simply glancing at which hubs had flags, instead of having to store too much detail in short-term memory. Once a hub regained all required resource tokens (See game guide in Appendix B), the flag piece was removed from the board.

It is interesting to note that the teacher-participants did not convey the need for a flag piece. During the R&D *Evaluate* phase (See Chapter Four), the student-participants did not come across this as an issue, either. However, education graduate students who played *Earthquake* as part of a class project in 2016 verbalized the need for such a physical piece as they used flag pieces. Without my intervention, the players together found and utilized the flag pieces in accordance to the rulebook, verbally expressing the usefulness of the piece to help remember which hubs were functional.

Summary of Design Recommendations

I took the insight from both the teachers and the engineers into account when I reflected on the design of the game as an instructional tool. The engineers appraised the content terminology and knowledge of earthquake engineering as adequate, further communicating that they had found no evidence of potential for the game to teach misconceptions about earthquake engineering to players. When I analyzed the feedback from the engineers with that of teacher interviews, I found they shared common themes, such as the need to clarify event card phrasing, to introduce more player roles, and to scaffold earthquake management. The teachers conveyed the high potential for the game to be relevant for use in classroom settings and offered suggestions specific to a teacher's perspective, such as developing an introductory video to acquaint students with how to play the game. The findings from this *Design* phase support the creation of the next *Earthquake* game version, which I described below in the *Implement* phase section.

R&D *Implement* Phase: Analysis and Findings

How will suggested modifications be addressed in the revision of the original prototype of the game? With *Instructional Systems Development*, a number of different sources furnished input towards instruction preparation, with the output being a product or procedure to be implemented (Dick, Carey, & Carey, 2001). Following suit, the teacher interview results and feedback from engineers provided me with feasible and minor modifications to the game.

The resulting implementations were descriptions of the three player roles (i.e., mayor, earthquake manager, and architect) and the associated player-role sheets corresponding to each role (See Appendix C). Since I altered the event cards to more clearly communicate their function, I also changed the game guide to reflect the alterations. Examples of several improved event cards are shown in Appendix D. Examples of player-role records may be found in Appendix C. And, the schematic for the actual board may be found in Appendix E.

Implementation of Player Roles

The most important adjustment to the game was my addition of player roles. I implemented the new player roles and associated record sheets to allow for each player to have an identity driven by task-specific responsibilities. This allowance for agency reflects the instructional scheme of social learning and the character autonomy of a well-designed game (Schell, 2015). With clearly defined job descriptions and tools to scaffold players to succeed in fulfilling job requirements, the players could more easily collaborate with one another as players construct their own knowledge about the urban infrastructure involved with earthquake engineering. I intended for clearly defined jobs for each player to help players more quickly familiarize themselves and each other with game logistics.

The mayor role. The mayor's job was to manage the board at the beginning of each round, outlined in the mayoral checklist (See Appendix C). For example, the water tower hub, represented by a blue solid triangle, produces one water resource token at the beginning of each round for any player to use as one action during that round. This function could have manifested on the board by the mayor placing a water resource token on top of the water tower hub token at the beginning of each round. The resource tokens were transparent, allowing the hub symbol underneath to still be visible.

The mayor's responsibilities also included monitoring each turn, making sure every player correctly followed the outlined turn sequence, and that every player took a turn. Additionally, the mayor would be responsible for recording the city building plans and general group goals. Each round, the mayor, the earthquake manager, and the architect reflect on the board and recap what hubs the group planned on building and reflects on the status of past goals. On a separate sheet of paper, the mayor can write down a sentence or two summarizing the group's progress from the previous round and intentions for the next round.

The earthquake manager role. I created the earthquake manager's job to facilitate disaster response whenever an earthquake card would be drawn, serving as a means for formative feedback and evaluation throughout game play. To respond quickly in the event of an earthquake, the earthquake manager would record the damage mitigation effects of each hub that would be built on the board. An example record sheet for the earthquake manager may be found in Appendix C for the scenario in which an upgraded fire station hub and an upgraded natural gas power plant hub have been built on the board.

Every time a new hub would be built, this would be recorded numerically according to how that specific hub would mitigate damage. For example, the fire station hub reduced earthquake damage on the entire board by one level for each sector. To record this, the earthquake manager would write "-1" in one of the outer hexagons of each sector on the board. If a group later would decide to upgrade the fire station hub, which would reduce the damage effect of an earthquake by two levels for just the fire station sector, the earthquake manager would write "-2" in the middle hexagon of the fire station sector on the earthquake manager record sheet (See Appendix C). When an earthquake would strike, the earthquake manager would facilitate the group to progress through the earthquake checklist on the game guide (See Appendix B). I implemented the earthquake manager record sheet to help the earthquake manager determine how many resource tokens would need to be removed from each sector.

The architect role. I created the architect role to use a similar scaled-down replica of the game board as the earthquake manager. The architect, however, would record where every resource token would be placed and what that resource token would be. The architect would record what hubs would be functioning on the board. Instead of recording numbers to aid in knowing how to remove resource tokens after an earthquake, the architect would record what types of resource tokens would be in each sector with "W" for water, "T" for transportation, "C" for communication, and "P" for power. The architect also would write down the name of each hub in that respective sector. An example record sheet for the architect may be found in Appendix C for the scenario I described above.

The architect would oversee the non-functional hubs by physically placing a flag piece attached to a token-sized base on top of any non-functional hub. A hub would be non-functional if its required resources would have been removed from the board (See Appendix A for non-functional descriptions in the rulebook). When a hub would become functional again, the architect would remove the flag piece from that hub.

I included in the architect job description an element of safety. Conceptualizations of engineering and safety were more transparent for the other two player roles. To balance the learning opportunity for safety involved in engineering, I included in the architect job description that the architect monitor ground conditions. Specifically, the architect would be responsible for monitoring risk if a nuclear power plant were to be built. For example, if a nuclear power plant hub would be built on the board and becomes non-functional, the architect would record each round that the nuclear power plant would be non-functional. I made this hub the only hub with time-sensitive functionality (See rulebook in Appendix A). After three rounds of non-functionality, the nuclear power plant hub would face meltdown if not upgraded with backup generators. I covered the concept of meltdown ramification in the rulebook and also included it within the scripted game-play for the production of the introductory video.

Implementation Phase Overview

In support of collective agency, I regarded the addition of distinct player roles as the most important implementation. I implemented each role to provide players with an area of expertise to establish a game identity, to foster autonomy, and to support entry into a discourse community of learners. Though important for game-play, clarification of event card phrasing was less of an instructional implementation and more of a game-mechanical adjustment. I produced the introductory video in accordance to teacher and focus group recommendations. Barry Hampe's *Making Documentary Films and Videos: A Practical Guide to Planning, Filming, and Editing Documentaries* (2007) was referenced to draft, script, and produce the video. I made the video specifically to show prior to student game-play during the *Implement* R&D phase (See Chapter Four).

Summary

Three years after taking on the challenge of creating an educational board game about earthquake engineering, I completed of the first four R&D phases of *Instructional Systems Design* (Dick, Carey, & Carey, 2001). By following the instructional template, I was able to transform my abstract conceptualization of a game into a functional physical product. Data for the first R&D phase, *Analyze*, consisted of literature from a number of books and research reports to provide the foundation for the development of the game. Data for second, third, and fourth phases (i.e., *Develop*, *Design*, and *Implement*) included video-recorded game plays, audio-taped conversations and interviews, and field notes from focus groups and from teachers. Serving as think tanks, the focus groups in the *Develop* phase assessed the instruction and mechanics of the game in real time. I supplied each focus group with earthquake engineering materials to guide infusion of content knowledge and processes into the game. I gathered the materials from the Earthquake Engineering Education Project (EEEP) design workshop held in the summer of 2011. This workshop laid the foundation for the STEM teacher workshop facilitated by EEEP in the summer of 2012. After implementing *Develop* and *Design* phase recommendations, I constructed the resulting version of *Earthquake* to engage players in 21st century learning by providing opportunities to participate in and improve critical thinking, scientific argumentation, and metacognitive abilities while exploring the relationship between natural systems, like earthquakes, and designed systems produced by humanity, like urban infrastructure.

Discussion

Invested in being of interest to the education community at large, in this research I acknowledged that "science education in the United States has become a subject of grave and pressing concern" (NRC, 2007, p. 1). To help address this concern, I aimed to improve science education through game-based learning by bringing an instructionally sound 21st century educational game into the classroom and the corresponding research into the literature base. In this chapter, I chronicled one way improvement can indeed effectively happen, and in doing so may help bridge gaps between practice and research.

Implications

The research methodology I employed captured game efficacy with respect to teachers' perceptions. Game developers have rarely mentioned that they included teachers in their discussions. Successful 21st century instruction requires teachers to be able to facilitate new standards (NGSS, 2013). Thus, teachers' opinions should be a key factor in educational game R&D. The Chapter Three research can contribute valuable insights to the field of game-based learning into how to make science and engineering design relevant and accessible to students, which is a goal of 21st century science learning (NGSS, 2013).

In this study, I provided detailed information about the use of the R&D process in game construction, employing feedback from numerous sources to revise and adapt the game to better fit the learning objectives originally established. Other successful R&D implications included multiple player roles for autonomy, using game-design prototyping tips, targeting a few specific learning theories to bound instruction, utilizing a collaborative-competitive multi-group scheme, being flexible with the non-linearity in an R&D process, and not getting too attached to any game component as it will more than likely change in one way or another. Form follows function. Just because game-based learning has been a buzz phrase does not mean every lesson should be about play.

This research may be especially significant for educational game designers by providing the field with a case study centered on R&D that synthesizes instruction- and game-design. More voices contributing to the process could help in constructing an instructionally sound game. Including teachers, gaming experts, and domain experts is particularly important for working out kinks and potential barriers to bringing the game into learning environments. I have been unable to find studies in the literature–only calls for the needed research (Bonanno, 2010; Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011). This study specifically contributes to educational game design by illustrating features of game-play and game mechanics associated with a functional prototype for 21st century learning as part of a coherent and complete R&D project.

Future Research

The next and final stage of the study was to evaluate the instruction of the game. I invited two groups of high school students to test play the game. In this final *Evaluate* R&D phase, the students were video-recorded during game-plays and I used a *game-based learning checklist* as an instrument to assign the degree to which performance objectives were met as students played the game.

Limitations

The R&D process of this study was limited to the 14 focus group members of the *Develop* phase, the 14 teachers interviewed and the test-plays with the two engineers in the *Design* phase. The study was also limited in that the teacher workshop lasted only one week. Implications and conclusions were therefore limited to the small size of the participants in the focus groups and the teacher game groups. The teachers who participated in playing the game and the subsequent interviews were already recruited for the STEM professional development workshop, and not specifically for game analysis, indicating a convenience sample rather than one scientifically chosen.

Finding sources to guide my holistic R&D process proved problematic. Few researchers designing educational games have reported completing phases in an R&D process. Few educational games have been designed with respect to an instructional or learning theory, with many equating engagement as justifiable evidence of successful learning. Further, my review of the literature (See Chapter Two) revealed game- and instruction-design as relatively separate research domains (Bonanno, 2010; van Staalduinen, 2011). Within and between both fields, there has not been an accepted agreement on the definitions of "game" or "play."

Inconsistent terminology and misrepresentations have pervaded the minimal research on game-based learning. I have found no studies explicitly detailing a full R&D process of educational game development. Few researches have reported results associated with an educational game not entangled with computer technology (see Rossiter & Reeve, 2010). Thus, my study was limited in terms of sources of available literature to use as references or guides to my R&D process.

Conclusions

Combining instruction- and game-design elements were essential for me to progress throughout the R&D phases. The more voices I integrated into the R&D process, the more effective *Earthquake* appeared to function as a game-based learning tool. The results of this study led to my conclusion that harnessing fun as a driving force throughout this specific R&D process helped sustain the authenticity of play in learning.

The conclusions of this study can contribute cohesion to the literature of educational gaming, a relatively uncharted area to which "[r]earch has only begun to build a body of experience that will make us believe in the value of playing and making games for learning" (Kafai, 2006, p. 36). In addition to enhancing 21st century cognitive abilities, an over-arching purpose of *Earthquake* is to increase STEM literacy and to help make STEM domains more relevant to students' interests by elucidating the STEM in everyday life. Accordingly, this research can contribute valuable insights into how to make STEM relevant and accessible to students. In this chronicled case study, I gave detailed information about ways to synthesize instruction- and game-design. Elements of game construction in completing four of five phases in a systems R&D process include: initial game construction, focus group involvement, game mechanics, learning theory, analysis of players' feedback, and game modifications resulting from input of game players and focus groups.

The content of this study and R&D approach to the creation of *Earthquake* can be of general interest to the field of science education. I addressed recently released expectations for K-12 science students by the National Academy of Sciences Committee on a Conceptual Framework for New Science Education Standards (NRC, 2012):

> …that by the end of the 12th grade, all students…possess sufficient knowledge of science and engineering to engage in public discussion on related issues; [and] are careful consumers of scientific and technological information related to their everyday lives. (p. 1)

With a goal to empower students to construct their own knowledge by collaborating with group members, arguing viewpoints, presenting evidence for decisions, and learning to be community-minded, the game can help serve as one of many educational components for students to meet these new expectations.

Instruction must be reoriented for 21st century science learning (National Research Council [NRC], 2011) to keep the United States globally competitive to lead, innovate, and create future jobs (*Next Generation Science Standards* [NGSS], 2013). Quality science education is fundamental to all Americans (NGSS; *National Science Education Standards* [NSES], 1996). Contemporary society demands a citizenry familiar with the complexity of real-world problems associated with societal systems coming into direct contact with the Earth's natural systems (Dede, 2007; NGSS, NRC). Particularly in urban areas, where natural Earth systems can seriously threaten human life and property, citizens must be educated to make informed decisions. The students in today's classrooms are the workers, policymakers, voters, and do-ers of tomorrow. We are responsible for providing today's students with tools, experiences, and knowledge guiding tomorrow's 21st century decision makers. How could we directly address this challenge? The answer can be found within teaching norms that have been employed for millennia; teaching norms applied in game-based learning today reemerge with a focus on 21st century learning.

CHAPTER IV

INDUCTIVE EVALUATION OF A 21^{ST} CENTURY EDUCATIONAL BOARD GAME

Games inherently foster the authenticity attractive for students (Miller, 2012) to engage in 21^{st} century learning (Prensky, 2014). Since games can function as an effective medium to embrace 21^{st} learning, game-based learning (GBL) offers a relevant context within which students can meet a variety of learning objectives (Barab et al., 2007). Real-life situations of a safer game-world afford players ways to enhance 21^{st} century abilities (Miller; Prensky, 2001; Rossiter & Reeve, 2010; Squire, 2002) and interpret society (Sukran, 2015)–valuable qualities in the existence of humanity as urban settings are becoming more prevalent (see Chapter Three).

The debate no longer focuses on whether or not GBL works (Hamari et al., 2015)–it does (Bonanno, 2010; Deen & Schouten, 2011; Miller; Oblinger, 2006; Rieber, 1996; Rossiter & Reeve; Schwartz & Bayliss, 2011; Squire; van Staalduinen, 2011). Teachers and other educational stake-holders, however, need evidence to fill knowledge gaps about specific efficacies of GBL (Barzilai & Blau, 2014; Davis, 2014; Perrotta, Featherstone, Aston, & Houghton, 2013). A conspicuous knowledge gap in GBL literature is research with empirical evidence of such needed educational efficacy

(Barzilai & Blau; Hamari et al.). We now ask how to carry-out more evidence-based GBL research (Barab et al.) for evaluating a game's educational efficacy (Bonanno, 2010; Ecker, Müller, & Zylka, 2011; Perrotta et al.).

Rationale

The 21st century is in need of new models of instruction to address the challenges educational researchers face for a rapidly changing society. The field of educational research needs instructional models that enhance students' abilities to learn from one another–models in which students simultaneously play and lean in real-world environments. The driving force for the rationale of this study is to advance science education research and methodology for game-based learning. Games are effective learning tools (Kebritchi & Hirumi, 2008; Van Eck, 2007). Well-designed games can provide opportunities for players to develop and practice important 21st century abilities (Prensky, 2001; Rossiter & Reeve, 2010; Squire, 2002) and scientific skills (NGSS, 2013), such as critical thinking, scientific argumentation, and metacognition (NRC, 2011, 2007a, 2000). These abilities have been regarded as essential to science education (NRC, 2011) and becoming an engineer (Viswanathan & Radhakrishnan, 2015).

Well-constructed educational games can blend engineering design and science (see Schwartz & Bayliss, 2011), which is an important new perspective adopted by the *Next Generation Science Standards* (2013). Within the safe realm of a playing space, students resolving cognitive disequilibrium can progress into individual and group problem-solving involved for scientific inquiry (Van Eck, 2007). Embedding play within a game grounded by social learning can satisfy players' motivational needs (Deen & Schouten, 2011) to participate in their own learning (Rossiter & Reeve, 2010).

Playing quality educational games can cultivate 21st century science learning. Abilities of systems thinking, small-group complex communication, generating questions, re-framing problems, and abstract thinking have been, however, culturally uncommon in American science classrooms (Windschitl, 2009). Extracting contextual relevancy from instruction weakens the foundation of science education (Barab et al., 2007). As 21st century instruction is process-oriented, evaluation of instruction can thus reflect a process-oriented schema to more clearly reflect that under evaluation (Reeves, 2006). The field of education needs contextually relevant evidence-based research about evaluation methodology for GBL. Bringing this study to the literature base can help bridge educational research methodology and actual practice of GBL for science education.

Problem Statement

Critical components missing in education research literature are guideposts to credibly evaluate educational games (O'Neil, Wainess, & Baker, 2005). The problem that the GBL community lacks evaluation research on games deserves to be addressed (Perrotta, Featherstone, Aston, & Houghton, 2013). The literature base does not provide sufficient evidence to link GBL with targeted performance objectives (Bonanno; Davis; Hamari et al., 2015; Perrotta et al., 2013). With scientific evidence of GBL effectiveness, educational stakeholders can be more aware of GBL benefits. Educational stakeholders need information to fill knowledge gaps about GBL evaluation (Driver, 2014).

Educational gaming researchers have called for more empirical evidence (Barab et al., 2007; Schwartz & Bayliss, 2011; Squire, 2002) on the effectiveness of games as learning environments (Federation of American Scientists, 2006) and on factors related to learning outcomes (van Staalduinen, 2011). The commonly used pre- and post-test (see Sabourin & Lester, 2014; van Staalduinen,) and survey evaluation formats (see Hamari et al., 2015), may not adequately capture how students interact with an educational game during play. This can fail to provide sufficient evidence about performance objectives (Schwartz & Bayliss). Traditional surveys and pre- and post-tests typically extract data outside the time-frame of the play-sphere, not during actual game-play. The evaluation of instructional design models should occur throughout the entire process, not just performed at the end (Braden, 1992). GBL is a process-oriented method (Bonanno, 2011). Thus, data captured during a GBL environment can be a more appropriate method to collect data.

Examining how aspects of student GBL experiences can occur is pivotal to GBL research (Sabourin & Lester, 2014). Researchers have called for evaluation of educational games in the form of a case study to research how students actually play to allow for emerging evidence of meaningful learning (Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011). Guideposts for evaluating a GBL instructional tool, however, are lacking in the literature base (Schwartz & Bayliss, van Staalduinen, 2011).

Purpose of the Study

My purpose in this research was to empirically study students' play as they engaged in a collaborative-competitive science education board game anchored in engineering design. With a primary focus on empirical evaluation of the game, I chronicled the research and development (R&D) of the game about earthquake engineering, called *Earthquake,* by addressing the five phases of an R&D process for instruction design (Dick, Carey, & Carey, 2001): *Analyze*, *Develop*, *Design*, *Implement*, and *Evaluate*. I built on the literature base by sharing a methodological approach to evaluating a GBL tool; in this case, evaluating the *Earthquake* board game for empirical results. I responded to the call for scientifically-grounded research of GBL evaluation, adding cumulative understanding to the field the nature of GBL evaluation.

In this study, I addressed the call for evaluation research of an educational game. This research can be significant for educational game designers since I concluded a thorough R&D case study. I have been unable to find similar research in the literature–only calls for needed research (Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011; van Staalduinen, 2011). I provided empirical results of this study with detailed information about elements of the effective game construction involved in completing the *Evaluate* phase of an R&D process.

Broader impacts of this study can inform stakeholders of how educational gaming supports successful 21st century science learning as related to critical thinking, scientific argumentation, metacognition, and engineering design. With my empirically validated evidence of the game's success, stakeholders could be more willing to view play as a legitimate way to learn. I can help elucidate the game's potential to school administrators, teachers, parents, and students that playing is an important part of 21st century life.

For the emergent research methodology, I coalesced features of instruction- and game-design, social and 21st century learning, and engineering and science education. I capitalized on the motivational essence of play to create an educational game. The domain anchoring the game was earthquake engineering. The complexities, systems thinking, collaborative discourse, and real-life relevancy of the domain of earthquake engineers offered an appropriate context for game development. The earthquake game provided players opportunities to practice and improve critical thinking, scientific argumentation, and metacognitive abilities as they constructed content knowledge about engineering. Improving higher-order thinking and acquiring knowledge about engineering design have been articulated as key aspects of 21st century science learning (NGSS, 2013). I created the earthquake engineering game in accordance with *Next Generation Science Standards* for a scientifically literate citizenry. My design of the *Earthquake* game provided players with opportunities to do engineering design and science, understand engineering and science, produce engineering knowledge and 21st century abilities, and to blend science knowledge with engineering design.

Research Questions

The approach here to solving the problem of a lack of empirical research hinged on evaluation questions. The point of the *Evaluate* phase was to find if there was evidence to support two knowledge claims of what can result from playing the

Earthquake game. Knowledge claim number one was that the game provided players opportunities to practice and enhance the 21st century STEM learning abilities of critical thinking, metacognition, and scientific argumentation. Knowledge claim number two was that the game taught fundamental earthquake engineering content knowledge. In accordance, the research questions were:

(1) How may evidence to potentially support the two knowledge claims be found and carried out?

(2) To what magnitude does any evidence support the two knowledge claims?

I developed these questions to give inference into the educational efficacy of *Earthquake* and into GBL research methodology. In these questions, I specifically targeted the fifth and final R&D phase, *Evaluate*, of the instruction design model (Dick, Carey, & Carey, 2001) previously addressed; Chapter Three covers the research design for the first four R&D phases: *Analyze, Develop, Design, Implement*. In answering the two research questions above, I concluded the R&D process for the *Earthquake* game.

Overview of Literature

Educational gaming has been a rapidly evolving field of increasing attention (Sabourin & Lester, 2014). While much of the GBL research community has made diverse contributions to the literature, educational stakeholders and those in schools have needed data geared toward literal practicality (Driver, 2014). Researchers have called for studies focusing on the utility of GBL for the development of specific educative outcomes (Bonanno, 2010; Schwartz & Bayliss, 2011). That is, the field has called for more evidence-based evaluations of GBL tools. The lacking information about this methodological issue in research design has hindered researchers to link GBL with evidence of learning outcomes (Perrotta, Featherstone, Aston, & Houghton, 2013) needed for educational stakeholders to make educated decisions (Driver).

Literature across domains and for ranges of age groups has inferred the effectiveness of GBL. Games have been utilized as methods of instruction for an array of areas (Sabourin & Lester, 2014) including scientific inquiry (Rowe, Shores, Mott, & Lester, 2011), mathematics principles (Conati, 2002), negotiation skills (Kim et al., 2009), argumentation (Easterday, Aleven, Scheines, & Carver, 2011), and critical thinking (Millis, Forsyth, Butler, Wallace, Grasser, & Halpern, 2011). GBL has been associated with encouraging various cognitive and psychomotor skills (Dempsey, Rasmussen, & Lucassen, 1996), strengthening spelling and decoding performance in kindergarten students (Din & Calao, 2001), helping primary school students with poor reading skills (Schwarz, 1998), and increasing language proficiency in ESL middle-school students (Herselman, 1999).

Games have long served as instructional tools in classrooms (Driver, 2014). Humans have been learning though play since recorded history (Huizinga, 1938/1980). Yet, the theoretical and research base have been lacking necessary for the establishment of practice, guidelines, and protocol (Rieber, 2001; VanEck, 2007). GBL research has underdone critiques that features in educational games can be superfluous to the learning task (Sabourin & Lester, 2014), only present for game mechanics (Mayor & Johnson, 2010). Authors have not agreed on the definition or parameters of GBL (Perrotta, Featherstone, Aston, & Houghton, 2013). Most researchers have coupled GBL and 21st century technology, like laptops or personal computers, while other researchers have suggested that face-to-face group play on a physical board game also stimulates 21st century abilities, like critical thinking and collaborative discourse (see Rossiter & Reeve, 2010).

Most research has relied on inference from psychological and educational theory rather than direct and sustained empirical evidence (Ceangal & McFarlane, 2006; Perrotta, Featherstone, Aston, & Houghton, 2013). The little research available on the efficacy of GBL primarily focuses on the development of specific competencies and connections to motivation, emotion, or affect (Sabourin & Lester, 2014). A common assessment format for those few educational games that have gone through an evaluation phase primarily reference only pre- and post-tests (see van Staalduinen, 2011) or appearance of engagement as valid evidence (see Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011) to claim instructional success–engagement and learning have been posited as not synonymous (Sabourin & Lester, 2014). Wording and exogenous factors can influence survey data, opening up degradations to weak methodological designs reliant on surveys (Saari, Johnson, McLaughlin, & Zimmerle, 1988). GBL merits further exploration that highlights empirical evidence of success (Schwartz & Bayliss, van Staalduinen) of the instruction itself under evaluation by a relevant process-oriented means.

Conceptual Framework

I oriented a socio-cognitive conceptual framework (Goldman, Petrosino, & Cognition and Technology Group at Vanderbilt, 1999; Zimmerman, 1995) for the evaluation of the *Earthquake* game with instruction organized for the development of 21st century cognitive skills and for content knowledge acquisition. I aligned my conceptual framework for this study in situated learning, social cognition, and socio-cognitive theory focusing on learning-by-doing (Barron et al., 1998) within the context of collective agency (Bandura, 2001) through sharing, defending, reflecting, and revising (NRC, 2007a). I further delineated a framework for the critical terms of "play" and "game" and the phrase "game-based learning" (GBL).

While a variety of definitions of the term "play" have been suggested, I followed conceptualizations proffered by Johan Huizinga. Others have derived a philosophically grounded framework generalizable enough for salient compatibility with classroom learning from Huizinga (Schwartz & Bayliss, 2011). A play theorist, Huizinga outlined one of the first recorded play platforms (Huizinga, 1938/1980): entry into play is a voluntary act, unable to sustain suspension or deference; play transcends ordinary life into a mystic consciousness; play requires order, through which rules should not be broken lest one becomes a spoilsport; and that productive play is socially rooted.

Huizinga has theorized that science and scholarship originally began in the form of games (Csikszentmihalyi, 1990). My definition of a "game" has reflected ideas of Huizinga and Csikszentmihalyi, who have conceptualized that "games fill out the interludes of the cultural script" (p. 81). Games have offered players more freedom to learn from mistakes, errors, and failures (Gee, 2003; Veen & Staalduinen, 2009). A quasi-bounded and socially justified arena of arranged potentialities that produce interpretable outcomes (Malay, 2007), a game can be a medium through which play functions (Bogost, 2011). "Game-play" has been considered an alternative to conventional schooling techniques (Perrotta, Featherstone, Aston, & Houghton, 2013). GBL invites players to apply deeper levels of knowledge and skills (Bloom, Englehart, Furst, Hill, & Krathwohl, 1956; Webb, 1997) while developing 21st century abilities (Galarneau & Zibit, 2011; Gee, 2009; Kirriemuir & McFarlane, 2004; Williamson & Sandford, 2011).

Methodology

Here in Chapter Four, I briefly overviewed four of the five phases of an R&D process (Dick, Carey, & Carey, 2001): *Analyze*, *Develop*, *Design*, and *Implement*. The fifth and final phase, *Evaluate*, during which high school students played the modified game, was my focus in Chapter Four. I recruited six high school students to play in two groups of three students each. Prior to game-play, I showed the introductory video that I produced in Chapter Three. I then video-recorded the two groups as the students played *Earthquake*; the students remained in their same game-group for both game-plays. I arranged one video-recorder per group. I then transcribed the video-recorded data into text format, including non-verbal communication as well as spoken. To analyze the transcriptions, I created a *Game-based Learning Checklist* to function as an instrument for me to gather empirical evidence of met learning objectives specifically for the *Earthquake* game. I coded transcription segments in accordance to the *Game-based*

Learning Checklist to record, using Microsoft Comments, instances of students having exhibited performance objectives: critical thinking, scientific argumentation, metacognition, and use of earthquake engineering content knowledge.

Functioning together as an instructional design, researchers have referred to the R&D phases as *Instructional Systems Development* (ISD) and have associated them with with contemporary views of instruction adopting socio-cognitive and situated cognitive theories (Dick, Carey, & Carey). Dick, Carey, and Carey developed their model as a general methodology for producing instruction. Both instructional novices and seasoned practitioners have utilized the model to produce instruction. Iterative and nonlinear, the model is an appropriate template for inductive projects (Dick, 1996) such as the R&D approach I have adopted here for evaluating an educational game.

Overview of Game Research and Development: Phases I through IV

***Analyze* phase.** Before creating instruction, I had needed to determine an instructional need. Thus before making the game, I analyzed relevant literature to locate research conducted previously, identify any literature gaps, and provide a strong foundation for the study. In the context of the game's R&D, I used the literature review from Chapters Two and Three of this dissertation, to serve and inform the *Analyze* phase, that is, to have conducted GBL literature review and to have writen performance objectives.

I determined earthquake engineering as the ideal domain on which to anchor the game. This complex and systems-oriented domain has several implications for 21st century science. These implications include blurring the domain boundaries between science and engineering (NGSS, 2013), providing opportunities to understand complex connections between Earth and man-made systems (NRC, 2011), inviting students' real-life experiences into the discourse of decision-making (NGSS), and empowering students to be producers of knowledge (NGSS, NRC 2007a). I determined the game's content knowledge performance objective to be that players can acquire introductory content knowledge about earthquake engineering.

I outlined the knowledge content performance objective to introduce earthquake engineering through a socio-cognitive constructivist lens. I adapted this perspective to allow players to construct their own knowledge frameworks in a GBL environment–an environment driven by the motivation of play within a community of learners. Zooming out, the overall performance objective of the *Earthquake* game was to engage players in 21st science century learning.

Well-designed games provide opportunities for players to develop and practice important 21st century abilities (Prensky, 2001; Rossiter & Reeve, 2010; Squire, 2002), such as critical thinking, scientific argumentation, and metacognition (NRC, 2011, 2007a, 2000; Perrotta, Featherstone, Aston, & Houghton, 2013). Well-constructed science educational games can blend science and engineering design (see Schwartz & Bayliss, 2011), which is an important new perspective adopted by the *Next Generation Science Standards* (2013). I determined broader performance objectives, pragmatically resonant with earthquake engineering, to be that players can gain the 21st century learning abilities of critical thinking, scientific argumentation, and metacognition.

***Develop* phase.** The game underwent basic construction processes inspired by focus groups in which experts from various backgrounds brainstormed and tested strategies, educational goals, and logistics. Focus groups consisted of science education researchers and graduate students, engineers, and those involved in gaming communities. The focus group incentive was to draft an engaging product that would hook students, allow them to become immersed in the context of the game, and to learn-by-doing. I video-recorded focus group meetings to reference decisions for the creation of a prototype version of *Earthquake*.

***Design* phase.** I included the completed prototype as an activity in a STEM (science, technology, engineering, and mathematics) teacher workshop. Fourteen teachers from across the U.S. played in four groups on the first and last days of the week long workshop. After playing the game, each group participated in an audio-recorded 30 minute interview to capture their playing experiences. Five open-ended research questions guided discussions about mechanics and educational relevance: *What did you learn about earthquake engineering from playing the game, what did you like about the game, dislike about the game, would change about the game,* and *how effective is the game at teaching the interconnectivity of urban infrastructure components?*

I transcribed the group interviews and analyzed them with constant comparison methods for naturalistic inquiry (Erlandson, Harris, Skipper, & Allen, 1993). The goal of analysis was to develop general categories that best captured the game's essence and indicated a need for modifications. I derived thought segments from transcriptions. I coded thought segments while constantly comparing code-categories to capture final emergent themes: *educational value, game logistics, playing experience,* and *classroom orchestration*. For organization purposes, I used identifiers for each thought segment contained to document the group, person speaking, question of topic, and transcription page number. I consulted science education researchers throughout the process to aid in minimizing potential bias and unforeseen threats to validity and reliability.

To validate findings related to interview analysis, I employed triangulation during the constant comparison analysis of the teacher interviews. I maintained a journal to record changes throughout the constant comparison process, and I recruited individuals of varying backgrounds for triangulation meetings. Furthermore, in the final stage of teacher interview analysis, I included a science education researcher who had served as an interviewer and a focus group member, an education graduate student unfamiliar with the game, and myself as the head game designer and developer. These three unique perspectives aided in establishing credibility within and among the themes, categories, and sub-themes (Erlandson, Harris, Skipper, & Allen, 1993) of the constant comparison. We met four times for several hours each.

***Implement* phase.** I generated a list of modifications and revised the *Earthquake* game on the basis of the teacher qualitative results. I found to add player roles to scaffold the learning process, to make an introductory video of how to play to supplement the rulebook, and to simplify descriptions on certain “event” cards. These forms of modifications essentially served to improve the game’s function as an instructional tool. I implemented the modifications directly by producing a brief introductory video and improving game logistics by clarifying sentences on targeted "event" cards and creating game-specific roles for each player. I physically created the modified game prototype, completing the *Implement* phase.

Overview of the modified game prototype. As students' prior knowledge critically affects learning (NRC, 2007), the I created the *Earthquake* game to harness such prior knowledge to enhance the learning environment. I targeted the educational goal with respect to earthquake engineering content knowledge to teach the interconnectivity of urban infrastructure components: water, transportation, communication, and power (Llinas, 2002). I targeted broader goals to provide opportunities for the development and practice of higher-order 21st century thinking skills. I embedded in the game targeted some of the most important of these abilities, which are critical thinking, scientific argumentation, and metacognition (NRC, 2011). *Earthquake* supported players to practice and improve these abilities in a way that addressed *Next Generation Science Standards* (2013) to infuse engineering design into science instruction.

Devised for three to six players per board with several games set-up in a classroom, the board consisted of sectors on which "hubs" were built by playing "resource tokens." I made the game for each game-group to work collaboratively together as a "city council team," competing against other groups engaged in playing their own games. I designed the game group schema to function as a pedagogical tool. Following Leemkuil (2006), I aimed to use the interaction within gaming groups as a method to improve collaboration and cooperation through group discussions and debriefing. Qualities of productive small group interactions, found in gaming groups, have been posited valuable aspects of 21st century science learning (NGSS, 2013; NRC, 2011).

I finalized that the shared objective of all groups playing the game is to build an inhabitable and resilient city in an earthquake-prone area of the world. Each group collaboratively decides which "hubs" to build and how, based on available resources. I made "hubs" to serve various functions; some mitigate earthquake damage while others generate "resource tokens." When an "earthquake" card is drawn from the "event" deck, players remove a number of "resource tokens" from the board randomly determined by a roll of the die. After about two hours, the group with the most "people points" wins. When a group builds a "residential hub," they receive "people points."

Game Research and Development: *Evaluate* Phase

In this cumulative and final phase, I collected data to examine possible evidence supporting the two knowledge claims of the game's educational efficacy. I analyzed data from students' game-plays to acquire any evidence supporting the claims that the game provides players opportunities to practice and improve critical thinking, scientific argumentation, and metacognition, while constructing content knowledge about earthquake engineering.

Participants and Data Collection

Six high school students (n=6) volunteered, with voluntary parental consent, to participate in the study. The visit occurred in 2013 in a southwestern college town. Three students comprised Group 1 and three students comprised Group 2. Students chose on their own in which group to play. Upon entering the room, three students sat at one table while the other three sat at the other table. Before the activity began, all six students appeared equally talkative amongst each other. The students already knew each other, being friends at the same local high school. Prior to game-play, I showed the teacher-recommended introductory video. The two groups then played *Earthquake* in the same room but on their own group table. The groups of students collaborated within their group to play the game, while competing against the other group at the other table.

The two groups played their own game for an hour and a half. I chose this timeframe based upon my qualitative field notes from the aforementioned STEM (science, technology, engineering, and mathematics) teacher professional development workshop that occurred a year prior. The teachers from this workshop were the R&D *Design* phase participants; teacher-participants had informally recommended the game last about the same time interval as a block schedule class (i.e., 90 mins). After a complimentary dinner break, the two student-groups played the game a second time. Players remained in their same groups for Game 1 and Game 2. Not only had I planned this in advance, the students specifically requested to remain in their same groups for Game 2. The students played the second game for an hour and a half, as well as the first game. I video-recorded game-play to capture how students played Game 1 and Game 2. One video camera recorded Group 1 while another video camera recorded Group 2.

Data Analysis

I transcribed the video-recordings and included player dialogue as well as relevant player non-verbal communication, such as actions pertaining to game-play (i.e., pointing to a “hub” built on the board instead of verbalizing a location). To analyze the video transcriptions, I developed a *Game-based Learning Checklist*. I used the checklist as an instrument to assess the degree to which players demonstrated use of critical thinking, metacognition, scientific argumentation, and earthquake engineering content knowledge. I developed the *Game-based Learning Checklist* to compare measurements of cognitive gain and knowledge acquisition between Game 1 and Game 2 for both groups of students.

Instrument development. Found in Appendix F, I used the *Game-based Learning Checklist* to tally each player’s demonstration of critical thinking, metacognition, and use of earthquake engineering content knowledge with respect to scientific argumentation components: making a claim, defending, clarifying, revising, and asking for input. I scored the players’ actions based upon categories I organized around the cognitive domains of critical thinking (Paul & Elder, 2007), scientific argumentation (C. Stuessy, personal communications, October 2013; NRC, 2007), self-regulation and control components of metacognition (Pintrich, Wolters, & Baxter, 2000), and earthquake engineering content knowledge (G. Fry, personal communications, July 2011, June 2013). I modified Paul and Elder’s checklist for the cognitive domains of critical thinking and Pintrich, Wolter, and Baxter’s checklist for metacognition to be utilized through a GBL lens within the context of scientific argumentation. Following educational game design recommendations from Schwartz and Bayliss (2011), I replaced the word "learning" with "playing" in Dick, Carey, and Carey's (2001) instructional design model to allow for the instructional design to transfer onto game evaluation. I created the *Game-based Learning Checklist* as an amalgamation of modified versions of other 21st century learning checklists reoriented with respect to play as a voluntary means to engage in learning.

I finalized the *Game-based Learning Checklist* categories to be critical thinking, metacognition, and earthquake engineering content knowledge. I compartmentalized these categories into subcategories, each with respect to scientific argumentation components. I determined my resulting subcategories for the critical thinking category to be: (1) raises a vital question and/or problem, (2) gathers and/or assesses relevant information, (3) comes to a well-reasoned solution, and (4) thinks open-mindedly within an alternative system of thought. I determined my resulting subcategories for the metacognition category to be: (1) plans by setting goals for playing and timing; (2) strategizes by deciding which strategy to use for a task or when to change a strategy; (3) regulates time use, effort, pace, or performance; and (4) regulates motivation, emotion or environment (i.e., volition control). I determined my resulting sub-categories for the earthquake engineering content knowledge category to be: (1) interconnectivity, (2) importance of water, (3) redundancy, (4) resilience, (5) human element, (6) safety, and (7) real-life applications

Instrument credibility. With help from other science education researchers, I established an inter-coder reliability of 87% for the *Game-base Learning Checklist*. A *Design* phase focus group member who also participated in the triangulation analysis of the teacher interviews, and I established the inter-coder reliability. We individually coded transcriptions with the *Game-based Learning Checklist,* followed by minor negotiations till we agreed 100% on codings. We independently transcribed the first 10 pages of Game 2 for Group 1. From my preliminary analysis, I found this portion of all the transcriptions yielded the most diverse and dense dialogue of all the game-plays. Once we determined the *Game-based Learning Checklist* passed an acceptable inter-rater reliability, I then employed the checklist as the instrument to capture features of the students' game-play associated with the established performance objectives.

Data analysis procedure. On the transcriptions of video-recorded game-plays, students exhibited evidence of having met learning objectives. When I identified an instance of exhibited evidence, I highlighted the corresponding segment of the respective transcription using a Microsoft comment. For each time a student exhibited evidence of a met learning objective, I highlighted that portion of the transcription with a Microsoft comment in which I labeled the respective *Game-based Learning Checklist* code. Each time I coded a datum, I wrote a tally mark on a physical print-out of the *Game-based Learning Checklist.* I examined student gains in learning outcomes by comparing the *Game-based Learning Checklist* tally marks I aggregated from Game 1 to the tally marks I aggregated from Game 2, for each respective group.

To accommodate the large amount of video data, I analyzed transcriptions every two pages; I read each page to sustain context throughout analysis. Upon completion of transcription analysis, I tallied the codes for each player onto the *Game-based Learning Checklist* for Game 1. I followed the same procedure to analyze Game 2. An example page of coded player transcriptions is shown in Appendix G. To examine *Game-based Learning Checklist* category gains, I compared between game frequency counts of *Game-based Learning Checklist* categories and subcategories for the two student game-groups.

Results

I analyzed the transcriptions of the video-recorded student-group game-plays using the *Game-based Learning Checklist*. I designed the checklist to measure the number of instances players exhibited use of critical thinking, metacognition, and earthquake engineering content knowledge with respect to scientific argumentation components. I filled out a *Game-based Learning Checklist* for each student game-play, totaling four completed checklists. I compared the spread and aggregated tally marks I recorded within and among both student game-groups. I found that aggregated tallies showed gains for each *Game-based Learning Checklist* category from Game 1 to Game 2 for both student-groups. I defined a "gain" as the difference between Game 1 and Game 2 tally counts between respective *Game-based Learning Checklists*.

I now present results for Group 1 and Group 2 organized below by *Game-based Learning Checklist* category. I describe the gains in which student-groups scored the highest in magnitude. I graphically represent gains to highlight inter-group dynamics with respect to each player. I label player results to include a player's group by number and the individual player's letter codename for their respective group. For example, I label results for player "A" in Group 1 is "Player1A." Results for "Game 1" and "Game 2" I labeled additionally, for example within a figure legend.

Critical Thinking

Group 1. The frequency counts for the subcategory "comes to a well-reasoned solution" were higher for each player in Game 2 than in Game 1. As shown in Table 4.1, the frequency count difference for the group was 171 counts (player A = 69, player B = 46, player C = 56), that is, the players showed a gain in coming to a well-reasoned solution through scientific argumentation components.

Table 4.1

Group 1 Counts and Gains for the Critical Thinking Subcategory of Comes to a Well-reasoned Solution

Critical Thinking	Game 1			Game 2		
Comes to a Well-reasoned Solution	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	8	14	13	32	38	37
Defend	12	12	12	22	16	18
Clarify	8	18	8	23	20	16
Revise	2	6	2	15	14	15
Ask	11	5	4	18	13	9
Within Game Totals by Player	41	55	39	110	101	95
Between Game Gains by Player	69	46	56			

Player 1A scored the highest gain between Game 1 and Game 2 for the subcategory "comes to a well-reasoned solution." Player 1C scored the second highest, followed by player 1B.

Figure 4.1 displays the spread of exhibited scientific argumentation components for each Group 1 player in coming to a well-reasoned solution. All three players exhibited similar relative gains.

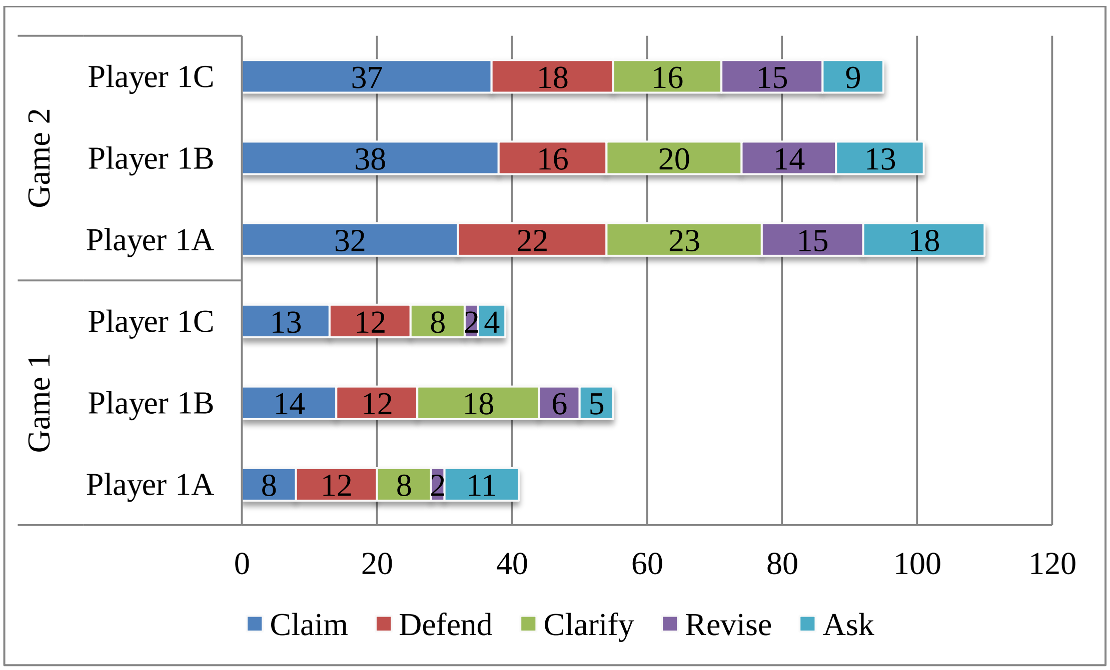

Figure 4.1. "Comes to a well-reasoned solution" subcategory spread of how players in Group 1 scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

In Appendix H, I show the other three subcategories of the critical thinking category displayed gains and similar spreads. The total Group 1 gain for the critical thinking subcategory “raises a vital question or problem” was 42 counts, for “gathers and/or assesses relevant information” was 82 counts, and for “thinks open-mindedly within an alternative system of thought” was 18 counts. Group 1’s total gain for the critical thinking category was 313 counts.

Group 2. The frequency counts for the subcategory “gathers and/or assesses relevant information” were higher for each player in Game 2 than in Game 1. As shown in Table 4.2, the gain for Group 2 was 340 counts. The players showed a gain in gathering and/or assessing relevant information through scientific argumentation components.

Table 4.2

Group 2 Counts and Gains for the Critical Thinking Subcategory of Gathers and/or Assesses Relevant Information

Critical Thinking	Game 1			Game 2		
Gathers and/or assesses relevant information	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	56	56	14	119	83	28
Defend	10	12	10	16	35	22
Clarify	20	20	6	73	54	23
Revise	12	9	4	23	22	7
Ask	17	12	3	44	38	14
Within Game Totals by Player	115	109	37	275	232	94
Between Game Gains by Player	160	123	57			

Player 2A scored the highest gain between Game 1 and Game 2 for the subcategory "gathers and/or assesses relevant information." Player 2B scored the second highest, followed by player 2C.

I show in Figure 4.2 the spread of exhibited scientific argumentation components for each player in this third subcategory of the *Game-based Learning Checklist* critical thinking category. Though players 2A and 2B scored higher gains with player 2C trailing behind, the dynamic of communication is reflected in both games as respectively parallel.

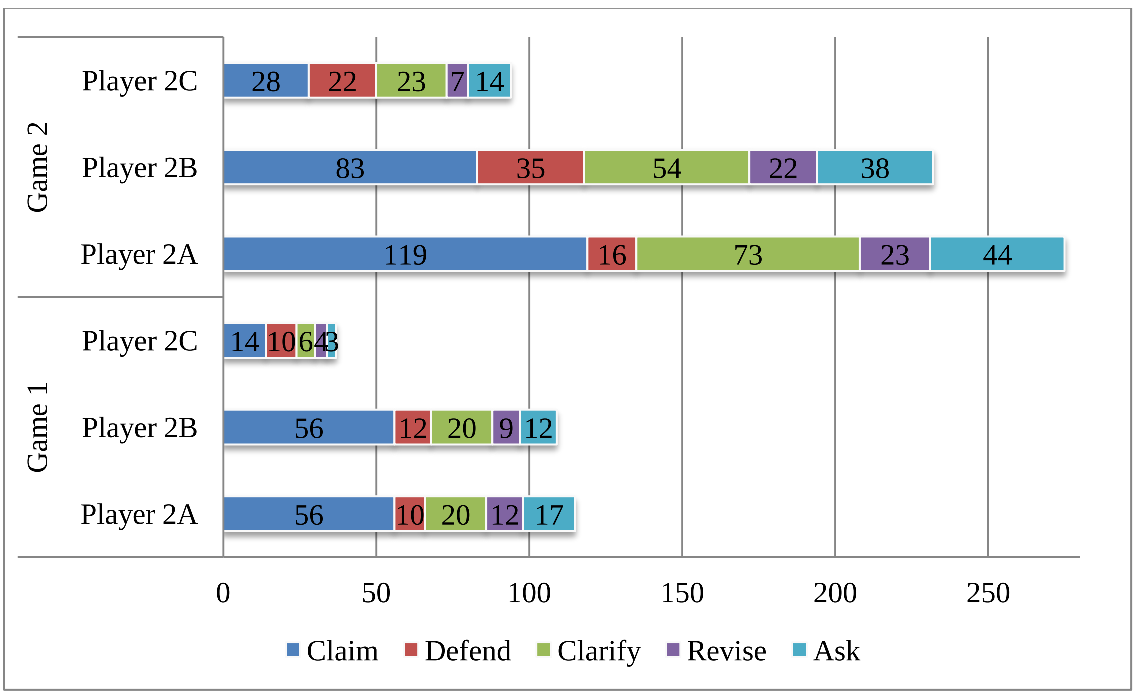

Figure 4.2. "Gathers and/or assesses relevant information" subcategory spread of how players in Group 2 scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

I show in Appendix I that the other three subcategories of the critical thinking category displayed gains and similar spreads. The total Group 2 gain for the subcategory "raises a vital question and/or problem" is 34 counts, for "comes to a well-reasoned solution" is 182 counts, and for "thinks open-mindedly within an alternative system of thought" is 12 counts. Group 2's total gain for the critical thinking category is 568 counts.

Metacognition

Group 1. The frequency counts for the metacognition subcategory of "regulates time use, effort, pace, or performance" were higher for each Group 1 player the second game than the first game. As shown in Table 4.3, the gain for Group 1 was 123 counts. That is, group 1 players showed a gain in regulating time use, effort, pace, or performance through scientific argumentation components.

Table 4.3

Group 1 Counts and Gains for the Metacognition Subcategory of Regulates Time Use, Effort, Pace, or Performance

Metacognition	Game 1			Game 2		
Regulates Time Use, Effort, Pace, or Performance	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	19	39	34	40	44	38
Defend	5	3	3	10	11	7
Clarify	11	5	7	23	21	21
Revise	3	6	2	7	11	8
Ask	16	18	11	26	28	10
Within Game Totals by Player	54	71	57	106	115	84
Between Game Gains by Player	52	44	27			

Player 1A scored the highest gain between Game 1 and Game 2 for the subcategory "regulates time use, effort, pace, or performance." Player 1B scored the second highest, followed by player 1C.

Figure 4.3 displays the spread of exhibited scientific argumentation components for each player in demonstrating this regulation. All three players exhibited similar relative gains.

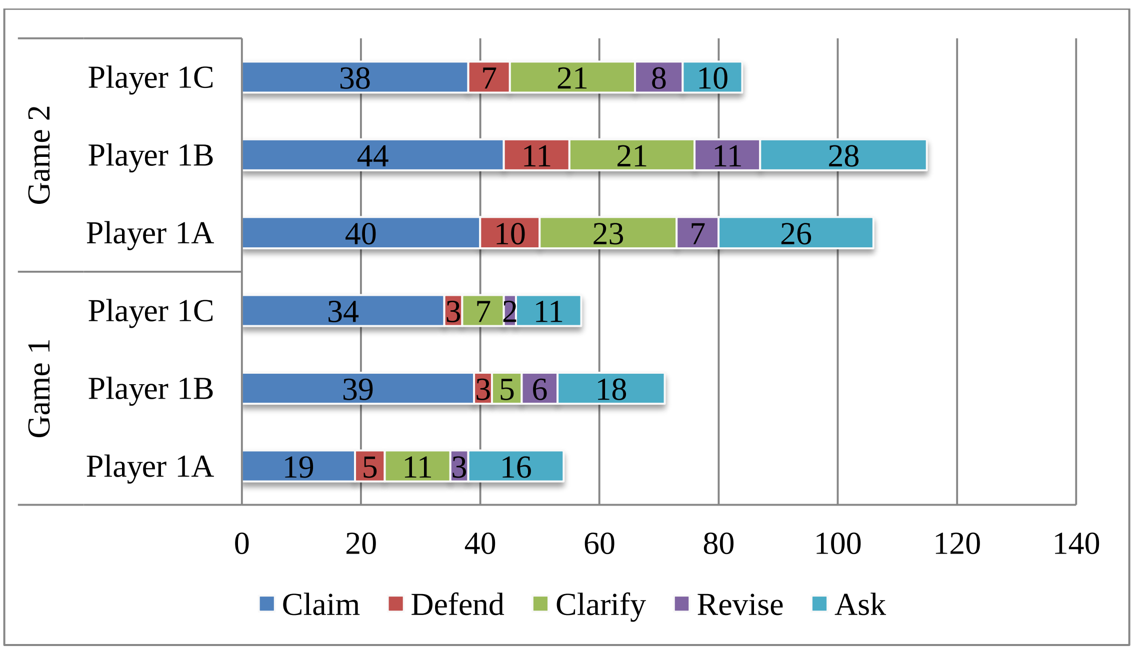

Figure 4.3. "Regulates time use, effort, pace, or performance" metacognition subcategory spread of how players in Group 1 scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

I show in Appendix J that the other three subcategories of the metacognitive category exhibited gains and similar spreads. The total Group 1 gain for the subcategory "plans by setting goals for playing and timing" was 75 counts, for "strategizes by deciding which strategy to use for a task" was 109 counts, and for "regulates motivation, emotion, or environment" was 43 counts. Group 1's total gain for the metacognition category was 350 counts.

Group 2. The frequency counts for the metacognition subcategory of "regulates time use, effort, pace, or performance" were higher the second game than the first game. Shown in Table 4.4, the gain for Group 2 was 343 counts. These players showed a gain in regulating time use, effort, pace, or performance through scientific argumentation components.

Table 4.4

Group 2 Counts and Gains for the Metacognition Subcategory of Regulates Time Use, Effort, Pace, or Performance

Metacognition	Game 1			Game 2		
Regulates Time Use, Effort, Pace, or Performance	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	72	40	13	130	79	26
Defend	7	6	6	17	19	17
Clarify	18	10	9	83	56	18
Revise	8	9	1	19	17	7
Ask	19	16	8	41	36	15
Within Game Totals by Player	119	81	37	290	207	83
Between Game Gains by Player	171	126	46			

Player 2A scored the highest gain between Game 1 and Game 2 for the subcategory "regulates time use, effort, pace, or performance." Player 2B scored the second highest, followed by player 2C to a considerable extent. Player 2C's gain was 27% that of player 2A and 37% of player 2B.

Figure 4.4 displays the spread of exhibited scientific argumentation components for each Group 2 player in demonstrating this regulation. Though the score of player 2C was substantially less of a gain than players 2A and 2B, the dynamic of communication between Group 2 players was reflected in Game 2 as having a similar spread as in Game 1; the individual relative magnitudes of gains was similar between Game 1 and Game 2.

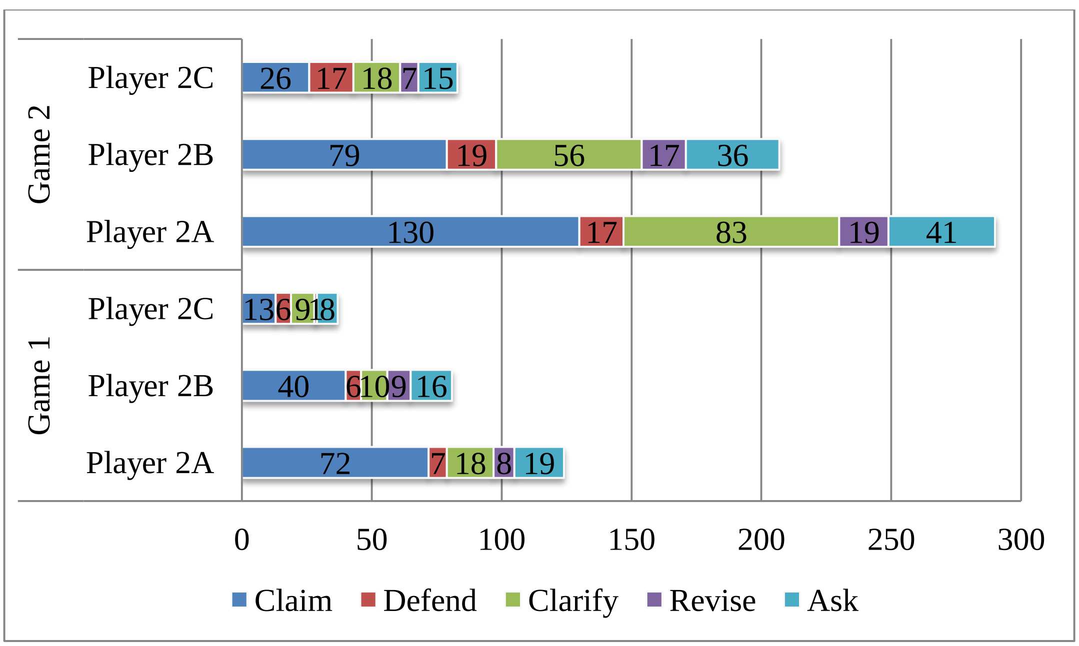

Figure 4.4. "Regulates time use, effort, pace, or performance" metacognition subcategory spread of how players in Group 2 scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

I show in Appendix K that the other three subcategories of the metacognitive category displayed gains and similar spreads. The Group 2 gain for “plans by setting goals for playing and timing” was 82 counts, for “strategizes by deciding which strategy to use for a task” was 155 counts, and for “regulates motivation, emotion, or environment” was -9 counts. I considered the former subcategory as a loss as opposed to a gain because the magnitude of the number nine was accompanied by a negative direction, mathematically. Group 2’s total gain for the metacognition category as whole, however, was 571 counts.

Earthquake Engineering Content Knowledge

Group 1. The frequency counts for the earthquake engineering content subcategory of “safety” were higher the second game than the first game. Shown in Table 4.5, the gain for the Group 1 was 27 counts. The players showed a gain in employing content knowledge about safety associated with urban infrastructure.

Table 4.5

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Safety

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Safety	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	0	2	1	8	8	3
Defend	0	1	0	4	0	3
Clarify	0	0	0	2	1	1
Revise	0	0	0	0	1	0
Ask	0	1	0	1	0	0
Within Game Totals by Player	0	4	1	15	10	7
Between Game Gains by Player	15	6	6			

Player 1A scored the highest gain between Game 1 and Game 2 for the "safety" subcategory. Player 1B and 1C had the same gain.

Figure 4.5 displays the spread of exhibited scientific argumentation components for each Group 1 player who demonstrated use of knowledge about earthquake engineering safety.

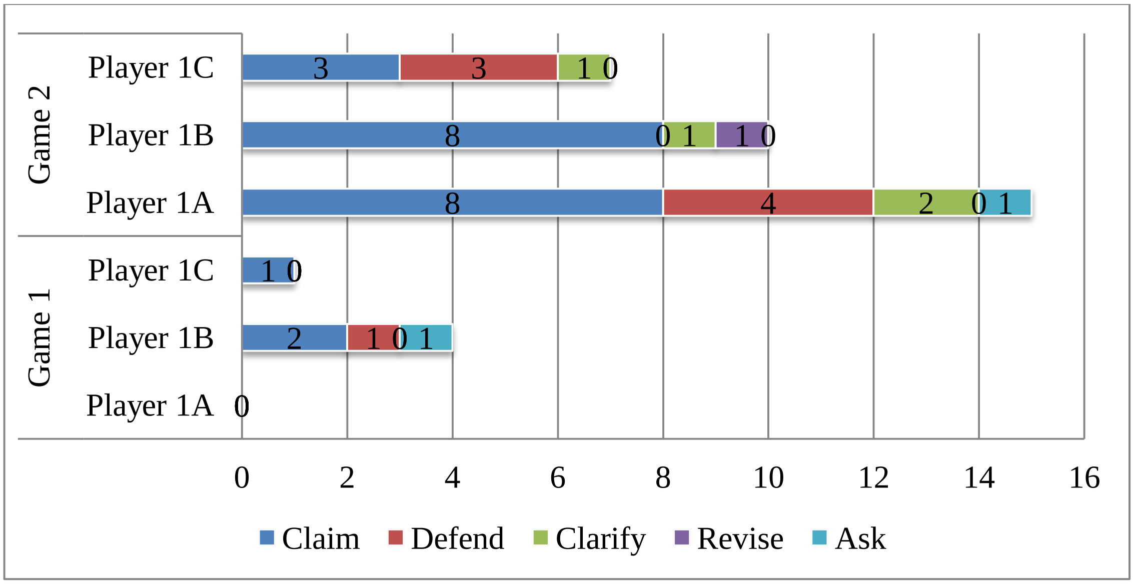

Figure 4.5. "Safety" earthquake engineering content knowledge subcategory spread of how Group 1 players scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

I show in Appendix L that the other six subcategories of the earthquake engineering content knowledge category displayed gains and similar spreads, except for the "redundancy" subcategory with a negative score. The total Group 1 gain for "interconnectivity" was 13 counts, for "importance of water" was 16 counts, for "redundancy" was -13 counts, for "resilience" was 19 counts, for "human element" was 11 counts, and for "real-life application" was 4 counts. Group 1's total gain for the earthquake engineering content knowledge category was 77 counts.

Group 2. The frequency counts for the earthquake engineering content knowledge subcategory of "human element" were higher the second game than the first game for Group 2. As shown in Table 4.6, the gain for Group 2 was 54 counts. That is, the players showed a gain in using content knowledge about the human element involved with urban infrastructure.

Table 4.6

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of the Human Element

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Human Element	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	4	4	2	17	8	4
Defend	1	0	1	2	5	1
Clarify	2	2	0	13	5	6
Revise	0	1	0	0	0	1
Ask	1	0	0	6	2	2
Within Game Totals by Player	8	7	3	38	20	14
Between Game Gains by Player	30	13	11			

Player 2A scores the highest gain between Game 1 and Game 2 for the “human element” subcategory. Player 2B and 2C score less than half the gain of player 2A.

Figure 4.6. displays the spread of exhibited scientific argumentation components for each Group 2 player who demonstrated use of knowledge pertaining to the value of human life.

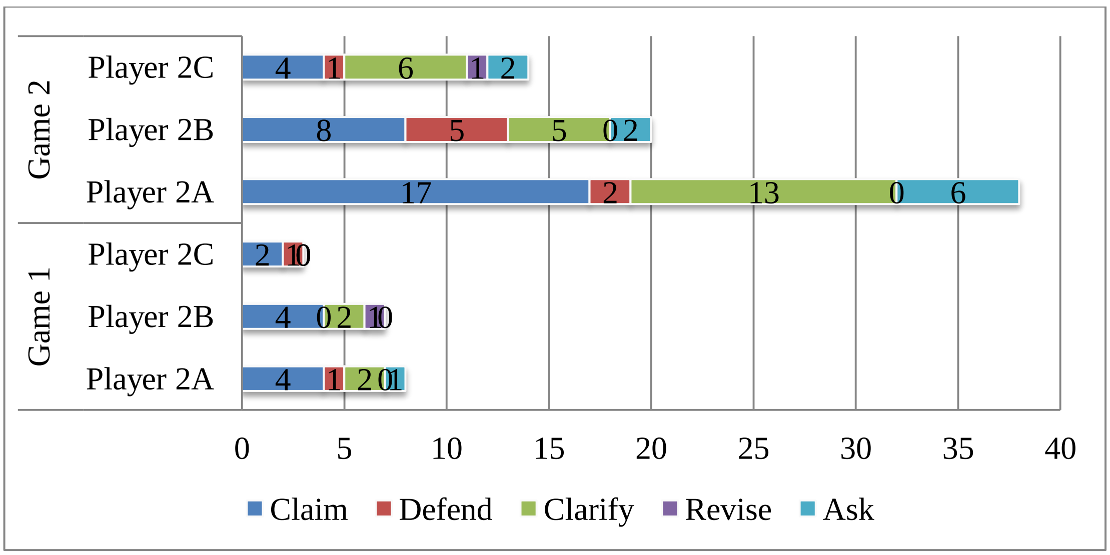

Figure 4.6. “Human element” earthquake engineering content knowledge subcategory spread of how Group 2 players scored a tally mark on the *Game-based Learning Checklist* with respect to scientific argumentation components: claim, defend, clarify, revise, and ask.

I show in Appendix M that the other six subcategories of the earthquake engineering content knowledge category displayed gains and similar spreads. Group 2's gain for "interconnectivity" was 27 counts, for "importance of water" was 13 counts, for "redundancy" was 13 counts, for "resilience" was 43 counts, for "safety" was 21 counts, and for "real-life application" was 16 counts. Group 2's total gain for the earthquake engineering content knowledge category was 187 counts.

Spread of Scientific Argumentation Components

I employed the *Game-based Learning Checklist* to measure the degree players used critical thinking, metacognition, and earthquake engineering content knowledge by how players exhibited engagement in scientific argumentation. I next partition results for a zoomed-out perspective, first by Group 1 followed by Group 2 results. I conclude the Results section with a total aggregate snapshot of between group gains.

As a creditability check for the analysis, I show that the gains in the proceeding section match the respective category (i.e., critical thinking, metacognition, and earthquake engineering content knowledge) gains in the preceding section. Group aggregate scientific argumentation components reflected similar spreads for Game 1 and Game 2, with Game 2 players having showed a higher magnitude of exhibited scientific argumentation for all three checklist categories.

Group 1: scientific argumentation of critical thinking. Shown in Figure 4.7, the critical thinking spread of scientific argumentation components exhibited by students reflected a similar between game dynamic. The gain was the area in the figure bounded between Game 1 and Game 2. The gain had a magnitude of 313 counts, the same magnitude as that found in the above Results section for Group 1's aggregate gain in the critical thinking I found through exhibited scientific argumentation. Group 1's gain in critical thinking peaked at "claim," "clarify," and "ask" for both games. Results from the second game indicated a larger relative gain at "claim" and "clarify."

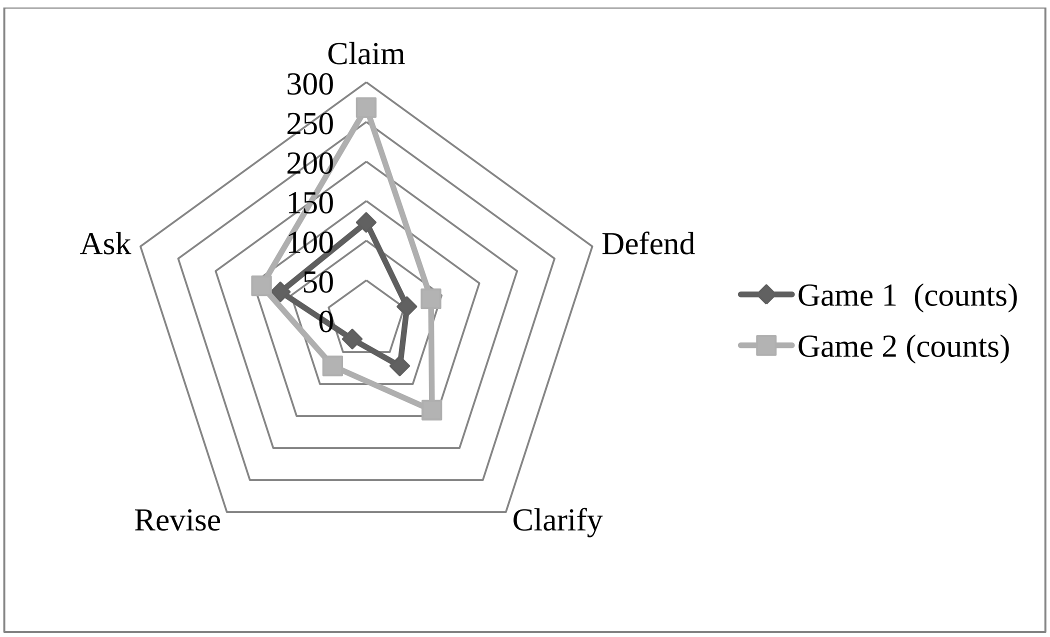

Figure 4.7. Snapshot of Group 1's exhibited scientific argumentation for the total critical thinking category. I measured scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist*.

Group 1: scientific argumentation of metacognition. Shown in Figure 4.8, the metacognition spread of scientific argumentation components exhibited by students reflected a similar between game dynamic. The gain was the area in the figure between Game 1 and Game 2. The gain was 350 counts. The spread of scientific argumentation components for Game 2 mirrored that of Game 1. The largest difference in metacognition frequency counts between games was at "claim."

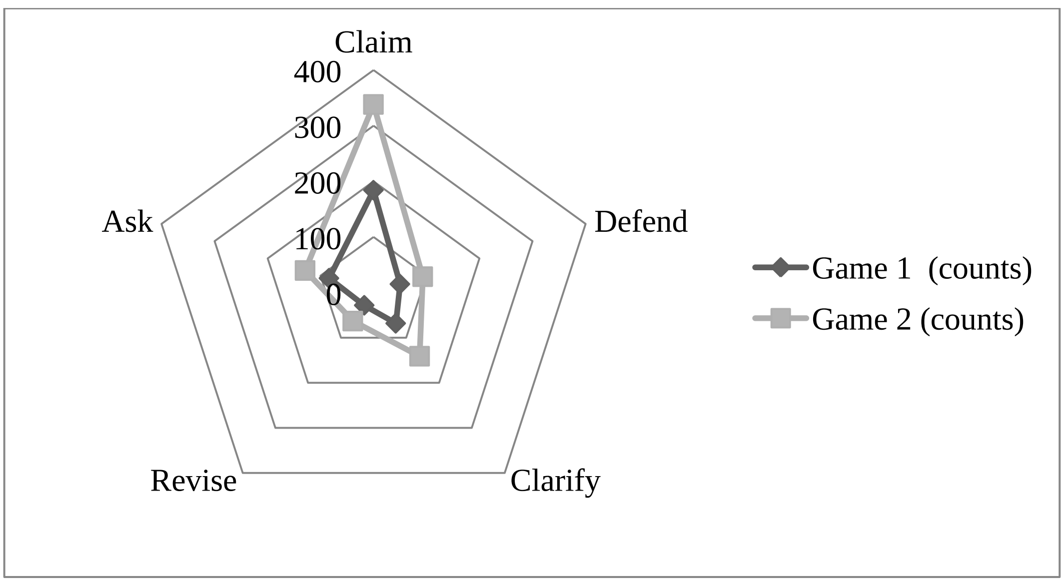

Figure 4.8. Snapshot of Group 1's exhibited scientific argumentation for the total metacognition category. I measured the scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist*.

Group 1: scientific argumentation of earthquake engineering content knowledge. Gain by game for the earthquake engineering content knowledge category as a whole is shown in Figure 4.9. I designated the gain as the area in the figure between Game 1 and Game 2. The gain had a magnitude of 77 counts. The largest difference in content knowledge frequency counts were at “claim,” followed by “defend” and “clarify.” The spread of scientific argumentation components for Group 1’s total earthquake engineering content knowledge mildly mirrored the counts from Game 1 to Game 2. Group 1 made considerably more claims in Game 2 than in Game 1, with respect to the total earthquake engineering content knowledge category.

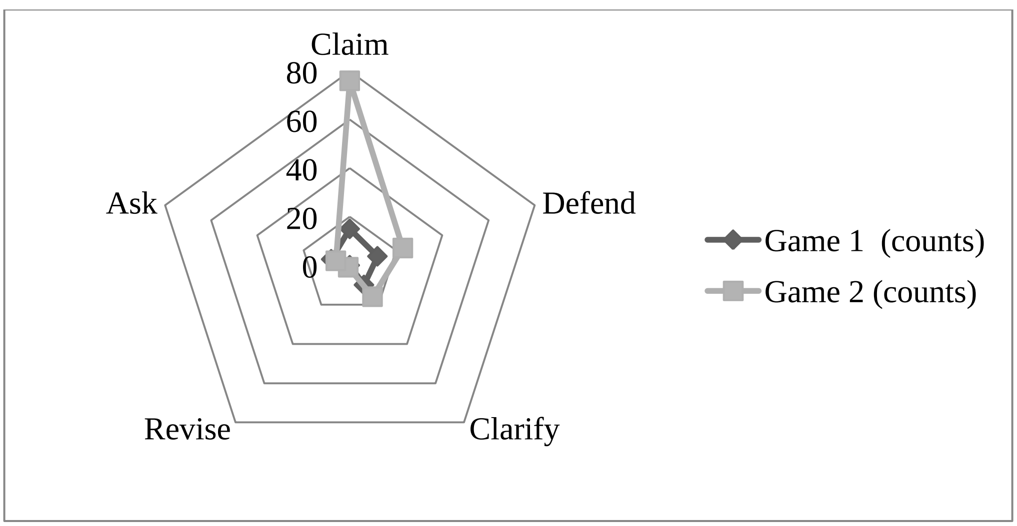

Figure 4.9. Snapshot of Group 1’s exhibited scientific argumentation for the total earthquake engineering content knowledge category. I measured scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist*.

Group 2: scientific argumentation of critical thinking. Gain by game for the critical thinking category as a whole is shown in Figure 4.10. I designated the gain as the area bounded between the dark gray line representing Game 1 frequency counts and the light gray line representing Game 2 frequency counts. The gain had a magnitude of 568 counts. The largest difference in critical thinking counts were at “clarify” followed by “claim.” The spread of scientific argumentation components for Group 2’s total critical thinking mirrored the frequency counts between Game 1 and Game 2.

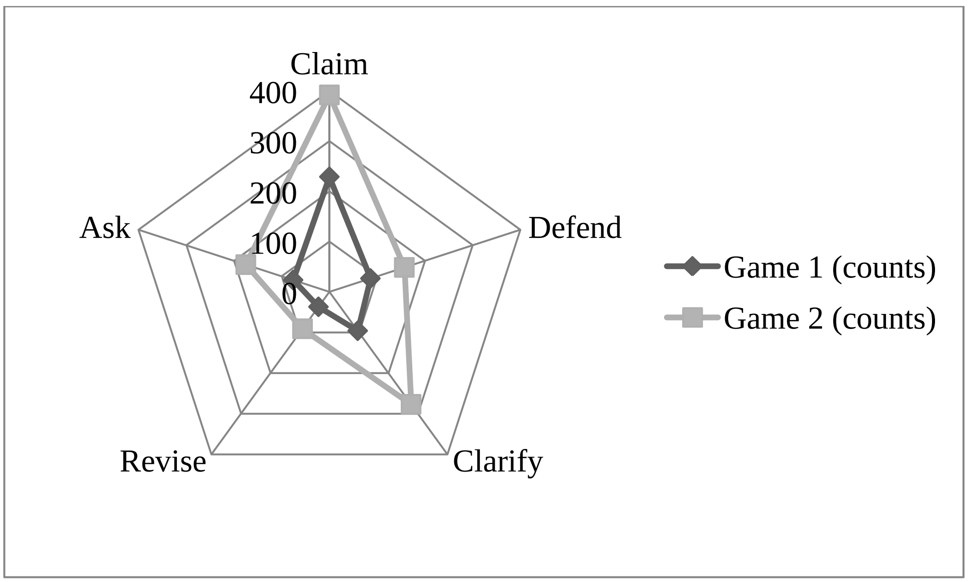

Figure 4.10. Snapshot of Group 2’s exhibited scientific argumentation for the total critical thinking category. I measured scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist*.

Group 2: scientific argumentation of metacognition. Gain by game for the metacognition category as a whole is shown in Figure 4.11. I designated the gain as the area bounded between the dark gray line representing Game 1 frequency counts and the light gray line representing Game 2 frequency counts. The gain had a magnitude of 571 counts. The largest difference in metacognition frequency counts were at “claim” followed by “clarify.” The spread of scientific argumentation components for Group 2’s total metacognition relatively mirrored the frequency counts between Game 1 and Game 2.

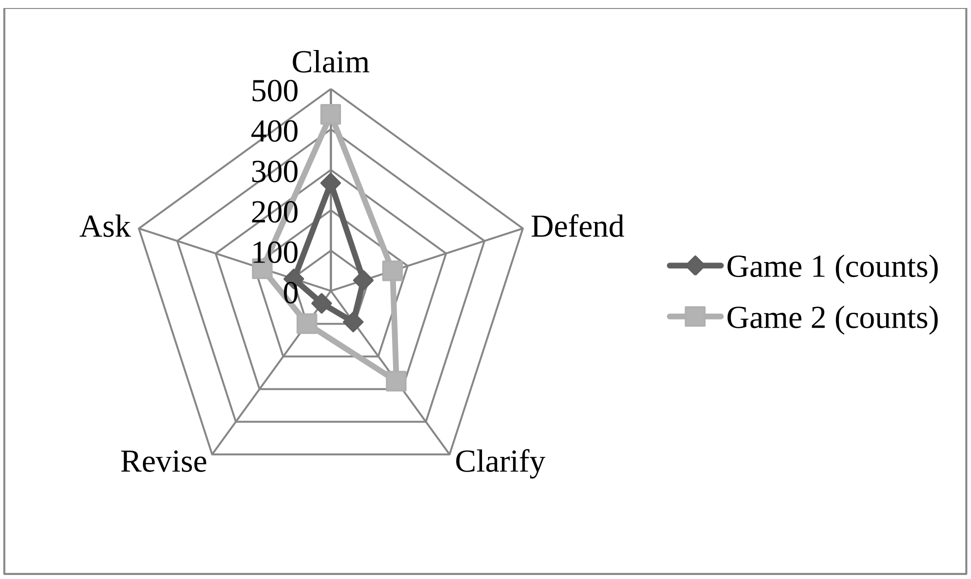

Figure 4.11. Snapshot of Group 2’s exhibited scientific argumentation for the total metacognition category. I measured scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist.*

Group 2: scientific argumentation of earthquake engineering content knowledge. Gain by game for the earthquake engineering content knowledge category as a whole is shown in Figure 4.12. I designated the gain as the area bounded between the dark gray line representing Game 1 frequency counts and the light gray line representing Game 2 frequency counts. The gain had a magnitude of 187 counts. The largest difference in content knowledge frequency counts were at "claim" followed by "clarify" and "defend." The spread of scientific argumentation components for Group 2's total content knowledge relatively shows mirrored frequency counts between Game 1 and Game 2.

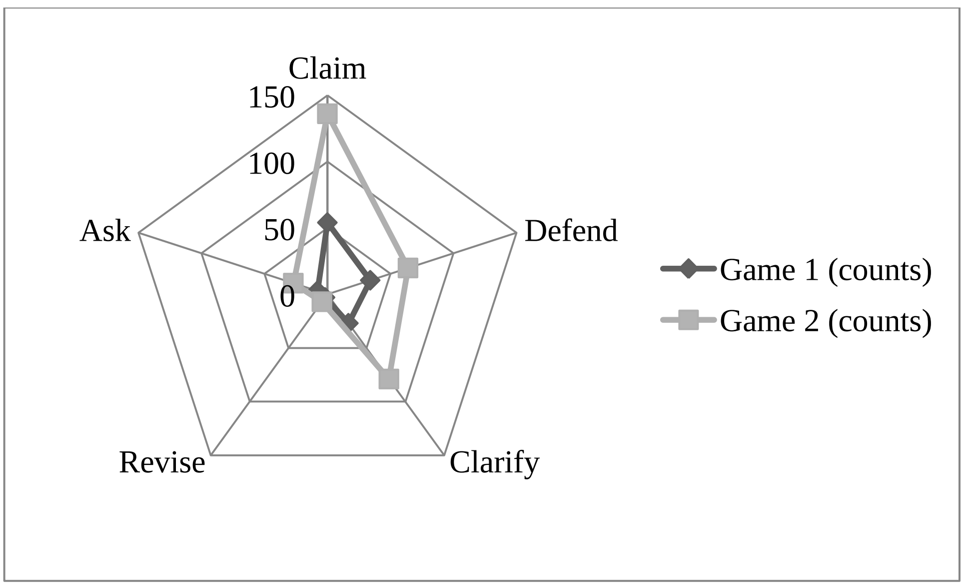

Figure 4.12. Snapshot of Group 2's exhibited scientific argumentation for the total earthquake engineering content knowledge category. I measured scientific argumentation components for Game 1 and Game 2 in counts derived from the *Game-based Learning Checklist*.

Group by group comparison: gain in scientific argumentation. Both groups exhibited gains for each scientific argumentation component. In other words, I recorded the difference in *Game-based Learning Checklist* tally marks (i.e., counts) as a positive magnitude for both groups. Figure 4.13 displays these gains for Group 1 and Group 2 on the same graph. The total group gain for Group 1 was 802 counts, graphically shown as the area enclosed within the dark gray line. The total gain for Group 2 was 1,326 counts, the area enclosed with the light gray line.

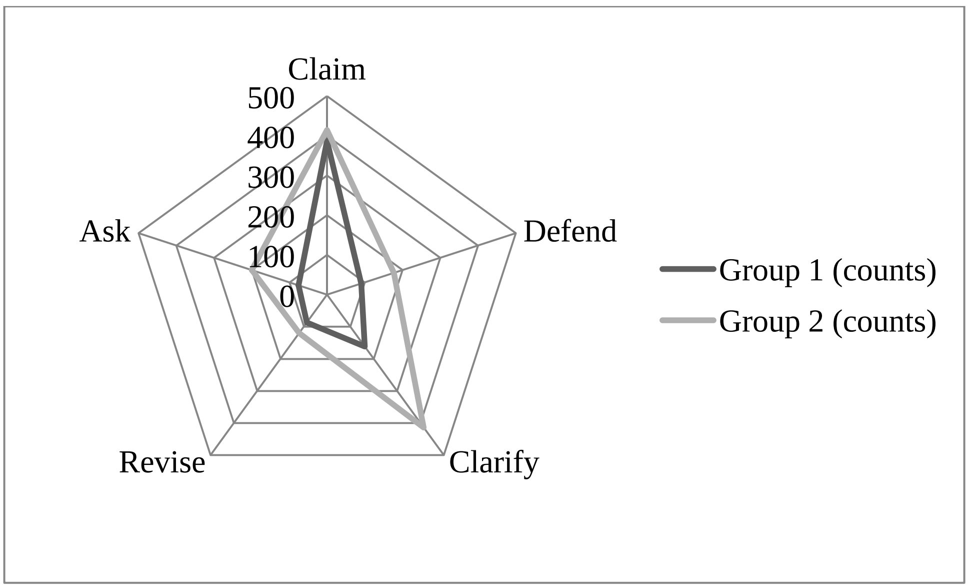

Figure 4.13. The difference in counts from the *Game-based Learning Checklist* between Game 1 and Game 2 for Group 1 (dark gray) and for Group 2 (light gray). I recorded the difference in counts as the gain for the respective groups' exhibited scientific argumentation.

The spread of scientific argumentation components was larger for Group 2 than for Group 1. Group 2's gains were larger in magnitude for all five argumentation components when compared to Group 1. I recorded peak gains for Group 2 from exhibited incidents of clarifying, making a claim, and asking. Lesser in magnitude, Group 1 peaked primarily at making a claim with a slight peak from clarifying. Group 2 gained 252 more frequency counts than Group 1 for "clarify," 124 more counts than Group 1 for "ask," and 87 more counts for "defend." Both groups' spread of scientific argumentation indicated about the same overall symmetrical distribution with respect to defending, clarifying, revising, and asking questions. From field notes and video data, Group 2 won Game 1 and Group 2 lost Game 2.

Summary of Results

The results I described above indicated that both groups of players exhibited more use of critical thinking, metacognition, and earthquake engineering content knowledge during their playing of the second game. The spread of scientific argumentation components I identified within each *Game-based Learning Checklist* category resembled similar trends. The spread for critical thinking between Games 1 and 2 closely resembled the same shape, as was the case for metacognition. I recorded a different dynamic in each group for the earthquake engineering content knowledge category; the spread of scientific argumentation did not clearly mirror my recorded number of observed incidences between games as was the case for critical thinking and metacognition. In other words, the earthquake engineering content knowledge category results did not indicate as close a resemblance in the spread of scientific argumentation between the two games as was the case for the critical thinking and metacognition categories.

I organized the results to yield information about the *Earthquake* game's educational efficacy. To make the aforementioned knowledge claims (see Research Questions section) that the game provides players opportunities to practice and enhance critical thinking, metacognition, and earthquake engineering content knowledge through scientific argumentation, I needed to support my claims with empirical evidence. Accordingly, I presented results to address: (1) how evidence to support knowledge claims can be found and carried out, and (2) what is the magnitude of evidence that supports knowledge claims.

In the locus of my first set of results, I addressed critical thinking, metacognition, and earthquake engineering content knowledge by student-groups. In the second set of results, I explicated the spread of scientific argumentation components, first by student-groups then by a total scientific argumentation gain graph. The two results sections together, I elucidated evidence to answer the research questions. The results yielded empirical evidence regarding information about elements of my effective game construction involved in completing the *Evaluate* phase of the employed R&D process.

Adverse event. As part of the day's event, I planned for a 30 minute break between the two games. Meals were brought in to give both groups a chance to eat and to take both a mental and physical break. The food, however, was delivered early while Game 1 still had about 15 minutes remaining. The one parent who attended the event announced that everyone could eat at that moment. One game group verbally requested to finish the game first. The other game group did not verbally respond, and continued playing the game. To respect the parent's request, I briefly announced to everyone that we could all eat at that moment and continue playing or we could all take a break at that moment. Students from both groups verbally requested to finish the first game before eating. I perceived that all players appeared to communicate agreement by either verbalizing an affirmation (e.g. "Yes, keep playing and eat later.") or non-verbal communication gesturing "thumbs up" or vertically nodding their heads. I then announced we would finish the game, but if anyone became hungry to please feel free to eat. After the first game concluded, the students ate and took their break.

Conclusions

As social creatures, we learn from each other. With dynamics of social learning integrated into analysis of game-based learning, my empirical evidence has indicated what many naturally feel. When we are having fun doing something, we are going to remember it better than sitting at a desk staring at the clock. I developed the *Game-based Learning Checklist* to capture evidence of 21st century learning through play with this notion in mind, that the driving force of play is fun.

Findings for Research Question One

How may evidence to support the knowledge claims be found and carried out? I employed my inductively developed *Game-based Learning Checklist* to document and compare evidence of met learning objectives. From my analysis of student game-plays, I found evidence of between game gains for critical thinking, metacognition, scientific argumentation, and earthquake engineering content knowledge. Findings indicated there was evidence of effectiveness of this particular instructional innovation in advancing students' knowledge and abilities in 21st century STEM education. The R&D methodology provided my with an appropriate, systematic framework for integrating research methodologies at every phase in the R&D process. Synthesizing instructional- and game-design principles aided my construction of the *Game-based Learning Checklist* and my utilization of it in this specific instance of evaluating an authentic game-based learning tool, that is, the *Earthquake* game.

Findings for Research Question Two

To what magnitude does potential evidence support the knowledge claims? Results indicated that all players exhibited improvements from their respective Game 1 to Game 2 over *Game-based Learning Checklist* categories. The gain (i.e., difference in counted tally marks on the *Game-based Learning Checklist* between games) for Group 1 as a whole was 802 counts. The gain for Group 2 as a whole was 1,326 counts. With this empirical evidence, I support my claim that the *Earthquake* game provided players opportunities to practice and improve 21st century abilities.

For the first game, students exhibited use of critical thinking, metacognition, and earthquake engineering content knowledge by means of scientific argumentation. With this piece of evidence, I support my claim that *Earthquake* provided players opportunities to practice the specified abilities and to apply acquired content knowledge. During the second game, students exhibited more use of critical thinking, metacognition, and earthquake engineering content knowledge by means of scientific argumentation.

With these findings, I support the claim that the game provided players opportunities to enhance these abilities; game-play provided opportunities beyond practicing 21st century abilities. *Earthquake* functioned as a medium to enhance 21st century abilities through play.

Discussion

Results indicated positive educative outcomes within a game-based learning environment, *Earthquake*. Results yielded empirical evidence supportive of my knowledge claims. Form my findings of all categories of the *Game-based Learning Checklist,* I have indicated students gained abilities and knowledge use from Game 1 to Game 2. In other words, students scored more tally marks aggregated over each *Game-based Learning Checklist* category from my analysis of Game 2 than from my analysis of Game 1.

All players showed improvements from Game 1 to Game 2. Because I oriented the *Game-based Learning Checklist* around scientific argumentation, I suggest that my results indicated that social learning may have contributed to improved critical thinking, metacognition, and earthquake engineering content knowledge. After all, I created the game, in part, to help players tap into social learning.

Critical Thinking

Since results from the critical thinking subcategory of “comes to a well-reasoned solution” for Group 1 indicated the largest gain in their critical thinking category, I conclude the players in Group 1 may have aided each other through scientific argumentation due to the social learning inherent in the game design. The other three critical thinking categories were more individualistic in nature, which may have accounted for the Group 1 gains that were not as high of a magnitude.

Results from the critical thinking subcategory “gathers and/or assesses relevant information” for Group 2 yielded the largest gain within the critical thinking category. From field notes, I observed that Group 2 jumped right into the first game faster than did Group 1. For example, Group 2 appeared more focused on playing the game quickly at the beginning of Game 1; Group 2 appeared to have spent more time focusing on building infrastructure, whereas Group 1 appeared to have spent more time at the beginning of Game 1 discussing how to play according to the “Rulebook.”

Metacognition

Results of the metacognition category analysis indicated both student-groups scored the highest in the metacognition subcategory of “regulates time use, effort, or performance.” I conclude this finding may have been associated with the competitive nature between game groups. During game play, students would often peek over at the other group’s table, making competitive comments. Results from this metacognition sub-category may also have yielded the highest scored gain due to the players monitoring each other’s player roles. In addition to asking for help in conducting a role, players on their own accord took the initiative to look after their fellow players. This may have been an effect of my addition of player roles, which was recommended by the teachers during the *Develop* phase of the R&D process.

Earthquake Engineering Content Knowledge

Results for the earthquake engineering content knowledge subcategory of "safety" yielded the highest gain of the earthquake engineering content knowledge subcategories for Group 1. I specifically integrated game mechanics to address this fundamental engineering principle. When a player articulated an appropriate concept of safety, I noticed game play went more smoothly when an earthquake occurred–as I had intended by the mechanics of the game. I found other important earthquake engineering content knowledge subcategories with high gains to be the "importance of water," "resilience," and "interconnectivity."

Results for Group 2 for the earthquake engineering content knowledge subcategory of "human element" yielded this subcategory as to having the highest gain of the earthquake engineering content knowledge subcategories for Group 2. As with the other subcategories, I specifically constructed the game mechanics to address that humanity has been a driving force for engineering. I based the winning condition of the game upon this notion. During Game 2, Group 2 appeared very focused on specifically building up their city to win the most "People points."

Earthquake engineering content knowledge results indicated mostly claims having been made. However, I found Group 1 gains in all subcategories but "redundancy" while I found Group 2 gains in all subcategories. I conclude this finding may have been due to Group 1 taking more time during Game 1 to specifically discuss the pros and cons of resource redundancy. Once a general strategy was agreed upon by Group 1, the topic was not verbalized by these players during the second game with enough rigor for me to code a transcription segment confidently as a player having addressed the "redundancy" subcategory. Additionally, to confidently code instances of exhibited use of earthquake engineering content knowledge, I needed to identify cohesive articulation to record a tally mark on the *Game-based Learning Checklist*. In my analysis of the critical thinking and metacognitive categories, I found that coding with confidence was easier to support with empirical evidence. My ability to identity exhibited critical thinking and metacognition instances was easier, in part, due to these categories not having been strictly bound to content conditions. This boundary condition I had set of requiring specific exhibited use of domain content knowledge may have accounted for the higher gains I recorded in the critical thinking and metacognitive categories for both student groups.

Spread of Scientific Argumentation

For both groups, I found that the spread of scientific argumentation components amongst players within their groups was more well-rounded for the second game than the first. I found reflection of this dynamic in both groups for Game 2 for all *Game-based Learning Checklist* categories as a whole. Form my observations, I concluded this may have been due to players feeling more familiar with game mechanics the second time around. From field notes and observations, I perceived that all the students appeared more excited for Game 2 to start than for Game 1 to start. For example, both groups counted down from ten to 1 seconds, after which several players from both groups stood up over their respective board game, rapidly articulating plans and assessment available resources. I perceived the momentum from the first game may have carried into the second game. To me, the players all appeared to exhibit more collaboration amongst their own group as well as constructive competition between groups during Game 2.

I found the shapes of the spread for critical thinking to have been similar for both games, with Game 2 having exhibited higher counts in all scientific argumentation components. I observed the same trend for the spread of scientific argumentation components for the metacognition category. I found that more asking occurred within the critical thinking category for both games when compared to metacognition and earthquake engineering content knowledge. I found that more claims were made in the metacognition category for both games when compared to critical thinking and earthquake engineering content knowledge. I concluded that this finding may have indicated that critical thinking superseded metacognition in players for this specific instance of the two *Earthquake* game-plays.

Limitations

I created the *Earthquake* game specifically for the R&D of this GBL tool, *Earthquake* the board game . Any results or implications I thus have limited to this study. The R&D process of this study was limited to the 14 focus group members of the *Develop* phase, the 14 teachers interviewed in the *Design* phase, and the six high school students of the *Evaluate* phase.

The study was limited in that the teacher workshop only lasted one week and the students played the game only twice in one visit. Any implications and conclusions, I have limited to the small size of the participants. The teachers who participated in playing the game and the subsequent interviews were already recruited for the professional development workshop, and not specifically for game analysis.

Few researchers designing educational games have reported completing an R&D process. Few reported educational games have been designed with respect to an instruction or learning theory, with many equating mere engagement as justifiable evidence of successful learning. Further, I revealed in my review of the literature that game-design and instructional-design have been regarded as relatively separate research domains (Bonanno, 2010; van Staalduinen, 2011). Within and between both fields, I have been unable to find accepted agreement on the definitions of "game" or "play." The lack of cohesive terminology and concepts within and amongst domains resulted in a lack of methodological research guideposts.

Implications

In this study, I directly have addressed the empirical evaluation of an educational game, helping fill a large gap in the literature base. My work may be significant for educational game designers by providing a thorough R&D case study. I allowed for the R&D to emergently evolve with respect to itself and not to any superfluously prescribed assessment scheme. Researchers (Rossiter & Reeve, 2010; Schwartz & Bayliss, 2011;

van Staalduinen, 2011) have identified the need for and call for such a study. From my reports of empirical evidence, I have provided detailed information about elements of game construction involved in completing the *Evaluate* phase of the R&D process.

Game-based learning environments have fostered learning while also promoting engagement (Sabourin & Lester, 2014). With the broader impacts of my study, I have provided empirical evidence to inform educational stakeholders of how GBL can actually support successful 21st century STEM learning as related to critical thinking, scientific argumentation, metacognition, and engineering design. Since I empirically validated evidence of the game's success, I have opened doors for stakeholders to make informed decisions for themselves. If brought into classrooms and the GBL literature, my work can elucidate to school administrators, teachers, parents, and students that playing is an important part of 21st century life.

CHAPTER V

CONCLUSIONS

Learning through play is a profound way to learn. To play is to learn. The ambiguity and abstraction of a play-space provides players opportunities to become empowered in their own learning process. In play, learners can decide for themselves when and how to toggle between learner-centeredness, community-centeredness, knowledge-centeredness, and assessment-centeredness.

We intuitively know we learn in play. Educational researchers, however, have not reported empirical evidence of the educational benefits for 21st century STEM education. Further, the notion of what play is has been regarded as something different from academic domain to academic domain. Few researchers have connected play with educational gaming. I conclude play is at the crux of successful game-based learning. And within my notion of play, I have built upon socio-cognitive theory, social learning, and fun as driving forces for learners to enter a play-sphere. I have aimed in this dissertation to provide educational stakeholders with enough reliable and credible evidence to include play in 21st century STEM education.

From the findings of my three research chapters, I have support for my knowledge claims that learning through play resonates with 21st century STEM learning. Abilities such as critical thinking, scientific argumentation, metacognition, and engineering design are needed to thrive in a collaborative, fast-paced, constantly evolving 21st century world. These abilities can be developed through play and used in game-based learning. We are social creatures. As individuals, though, we have unique needs. A well-designed game aids players to manage solutions involving individual and group needs.

What qualities are inherent in a well-designed educational game? My main goal of this dissertation has been to create a well-designed educational game for 21st century science learning. To accomplish this, I first conducted a literature review of play and learning. After finding disjointed use of terminology and conceptualizations of what it means to play, learn, and function in a game-based learning environment, I became aware of the need to conduct a holistic research and development process to make an educational game for 21st STEM century learning.

In the following concluding sections, I present my findings through a zoomed-out lens. How do play and learning relate in the context of this dissertation? How do I carry out the creation of a 21st century science education game? And, what empirical evidence is there that indicates the game is educationally effective?

Zooming Out: Clarifying the Big Picture

What is Play and How It Connects to Learning

I proposed for my review of the literature neither to reconstruct nor to build upon conflictions about play and learning in an attempt to propose a unifying theory. Rather, I proposed to deconstruct our understanding of educational gaming to its core by exploring the essence of play as we know it. The guiding question of the literature review, therefore, remained general: *What is play and how does it connect to learning?*

In my answer to the guiding question, I can now link the generalities apparent in the literature to the findings I generated from the R&D process to explain how I believe this research has advanced our understanding about what was currently known about regarding the connections of play and learning. In other words, in this chapter, I have extended what my synthesis from the literature about the original state-of-the-state in terms of play and learning to include new knowledge claims about how this research has elucidated notions about play and learning.

Chapter Two: Literature Review on Game-Based Learning

Methodological diversity is lacking in GBL research. A pervading incoherence of terminology within and among domains has hindered GBL researchers to collaborate and corroborate findings. Few researchers have reported studies on underlying foundations of GBL. That is, few researchers have reported conceptual or theoretical frameworks regarding ideologies of what it means to play, to play a game, and to learn through a game by playing.

Some GBL researchers do not acknowledge the significance of play in making a quality educational game. I claim play is an essential factor when fostering a GBL environment. Some GBL researchers do not include game-design principles when designing an educational game. I claim that to make an educational game, principles about game-design should be included in the process of making an educational game. Further, to make an educational game, instruction-design principles should be included in the process of making an educational game.

The field of GBL lacks this necessary synthesis of instruction- and game-design principles, a cohesive set of consistent terminology, and a basic foundation of guideposts. For example, some researchers claim GBL began in the 1980s for US Air Force training. Others have claimed learning through play has existed since recorded history.

After my literature review, I have more insight as to why a dogma surrounds GBL as just a trend. Researchers have been using the buzz-phrase of GBL without integrating or acknowledging philosophical, historical, epistemological, or socio-cognitive foundations. I conclude that a "game" is a medium through which "play" manifests. Leaving the notion of play out of the picture reduces the authenticity of an educational game. The point of a game is to play; the point of an educational game is to play and learn from the play. GBL is not about taking a good lesson and turning it into a game because gaming is a buzz word; the lesson and content suffer when this is done. A well-designed game is created holistically, not contrived in accordance to fit a grant or standardized learning protocol.

A startling absence in GBL research is empirical evidence of educational games' efficacies as instructional tools. This is not too shocking since I have not found studies inclusive of an R&D cycle, nor an abundance of researchers synthesizing instruction- and game-design. GBL offers too much potential for 21st century learning for me to not fight back by providing the field structured and scientifically-grounded work.

The field of educational research needs more studies on GBL for empirical results as part of an R&D cycle. In grounding the creation of a GBL tool within the scope of an R&D process, validity and credibility can be attained to a much higher degree.

What the R&D Process Looked Like in Developing an Education Game

In this dissertation, I also addressed research questions specifically for the R&D of the *Earthquake* game I created. My main goal in conducting the R&D was to generate an instructionally sound educational game anchored around earthquake engineering to explore the interactions of play with learning embedded within an educational setting. I chose a qualitative research strategy for a case study that followed the instructional design template proposed by Dick, Carey, and Carey (2001), which consisted of five phases: *Analyze, Develop, Design, Implement,* and *Evaluate*. Dick, Carey, and Carey developed the R&D model as a general methodology for producing instruction, which has been used by both instructional novices and seasoned practitioners (Dick, Carey, & Carey, 2001). Iterative and nonlinear, the R&D model has been an appropriate template for inductive projects (Dick, 1996).

The instructional design scheme of Dick, Carey, & Carey (2001) structured the foundation for the R&D process I employed in these studies, but not without adaptations to "fit" the gaming scenario I would use as the "intervention" for my investigations.   I followed the educational game-design recommendations from Schwartz and Bayliss (2011) to choose to replace the word "learning" with "playing" in the original instructional design scheme. Additionally, I chose to follow a case study design to carry out the study. I also employed qualitative and empirical modes of R&D in an attempt to illuminate my creation of a revised R&D model that combined instruction-and game-design. In that regard, I superimposed game-design principles onto the R&D instruction-design model within each of the five R&D phases.

To inform my development of the first version of the game, I conducted a series of focus groups engaging game designers. I then orchestrated the play of a first version of the game with teachers attending a professional development workshop on earthquake engineering. With these teachers' input and additional input from engineering content specialists, I then made revisions before administering the game to high school students, who played the game twice. The students and I met in one session lasting a total of four hours.

I drew the research data in this dissertation from two main sources: (1) audio-recorded, post-play teacher focus group interviews, and (2) video-recordings of students playing the modified version of the game. I first transcribed and analyzed teacher group interviews through constant comparative methods for naturalistic inquiry (Erlandson, Harris, Skipper, & Allen, 1993) with the goal of developing general categories that best captured the game's essence and indicated needs for modifications. My analysis of teachers' interviews informed my modification of the game, which students then played. I made video-recordings of students' game-play and then transcribed the video-recordings, seeking evidence of advances in students' learning from their initial to final game plays. To analyze the student transcriptions, I created the *Game-based Learning*

Checklist, which functioned as an instrument to capture evidence of students' performance in the areas of interest: critical thinking, metacognition, scientific argumentation, and use of earthquake engineering content knowledge.

My guiding research questions for the second part of the dissertation dealt with the modification of Dick, Carey & Carey's (2001) R&D process to include a number of questions about process. I used these questions to structure my conclusions about what I learned about play and learning from the modified R&D process: (1) What major steps will I need to modify in a typical R&D process to develop a prototype for an educational game? (2) What major steps will I need to take to inform the original design of the game prototype and then pilot test the prototype? (3) What steps will I take to make modifications and revise the prototype of the game before testing it with high school learners? (4) What evidence from game play exists that students have improved abilities in critical thinking, scientific argumentation, and metacognition, and understanding of earthquake engineering content knowledge? (5) What input from the final phase of the R&D process informs any further game revisions?

Chapter Three: The Research and Development of an Educational Board Game for 21st Century Science Learning

After progressing through four of the five phases of Dick, Carey, and Carey's (2001) research and development (R&D) model for the construction of instruction, I conclude that an R&D process should not be rushed. Start out with a physical board game. In this specific case of *Earthquake,* teachers recommended preserving the physical arrangements of the board and to not digitize the game. If the game were to be digitized, I would now have enough information, however, to code a functional game–as opposed to if I had begun coding at very beginning when logistical kinks had not yet been worked out.

I conclude that multiple voices should be included in an R&D process. The more and diverse the voices were that I included in the R&D process, the easier it became to iterate and toggle between R&D phases. This is important since effective R&D processes are non-linear.

The more I synthesized game- and instruction-design, the more authentic the *Earthquake* game appeared to became in regards to playing and learning. That is, in using principles from both domains, the easier I found identifying problems and solutions to be. I more easily progressed through the development of the *Earthquake* game by incorporating individuals with differing backgrounds in the focus groups in the *Develop* phase.

In the *Design* phase, teachers shared their feedback as experts from the environment in which I made *Earthquake* to function. I implemented their recommendations into the game. Without the teachers' voices, I would not have had pragmatic feedback to help myself bridge my research with actual teaching practices. The teachers were in a way like gate-keepers. If the instructional tool, in this case the *Earthquake* game, had been deemed impractical by teachers, the game would not be versatile enough to enter schools and be educationally effective for 21st century STEM learning. By implementing teacher feedback, I was able to facilitate game-play with students.

In retrospect, had I not implemented feedback from the teachers and input from the engineer test-players, the last R&D phase (i.e., the *Evaluate* phase I discuss in Chapter Four) I conducted would have been fragmented and extremely difficult. Without implementing feedback from these diverse voices, the *Evaluate* phase could have been too fragmented for me to gather appropriate data. Further, the student-participants may have not been able to complete both test-games due to cognitive overload. The student-groups that played the game needed the scaffolding I supplied from the teacher feedback. And for my own sense of self-efficacy, I may have become too overwhelmed during the student test-plays to facilitate data collection had I not had the go-ahead from the content experts (i.e., the engineer test-players) and the context experts (i.e., the teacher test-players). I conclude that educational game-designers should include feedback from experts of the content knowledge embedded within an educational game and from the experts who represent the target population of those who would be facilitating game-play. Including a variety of voices is necessary for the construction of a well-designed 21st century educational game.

Chapter Four: Inductive Evaluation of a 21st Century STEM Educational Board Game

From the empirical results of this study, I conclude *Earthquake* is an educationally effective GBL tool. From playing the collaborative-competitive game, students exhibited evidence of practicing 21st century STEM learning. Upon comparing between-game results, I conclude that the student-test players not only practiced 21st century STEM abilities, but also improved specific content abilities. Results indicated students exhibited more signs of engaging in critical thinking, metacognition, earthquake engineering content knowledge, and scientific argumentation during the second game-play than during the first game-play.

Why did the student-participants exhibit empirical evidence of 21^{st} century science learning from playing the game? I conclude a contributing factor is the inherent fun involved in playing. During the student test-plays, I felt an excitement in the air. The students requested to keep playing at the end of the first game and requested to keep playing at the end of the second game. I conclude that the collaboration within each group and the competition between the two groups nurtured and sustained the feeling of fun, socio-cognition, and social learning as a driving forces to keep playing the game. I conclude *Earthquake* is an authentic educational game in part because it is fun and rooted in socio-cognition and social learning. And fun is the essence of play, while productive play is socially rooted.

Final Remarks

The further along in this dissertation that I progressed, the more I found myself playing in my research. I recommend that playing aids in reducing ego-boundaries. Playing fosters a flow state. By freeing myself of rigid boundaries, I played with the R&D phases. I conclude playing helped me to think abstractly when appropriate and concretely when needed. Playing helped me zoom in and out of the R&D phases, shifting the grain-size of stages in the research. Play can be a profound way to learn and to conduct research for 21^{st} century STEM learning. The play-factor in our society deserves to be acknowledged and nurtured for productive growth of our civilization.

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APPENDIX A

THE RULEBOOK

COMPONENTS

RESOURCE TOKENS:
Water — Transportation — Communication — Power

HUB TOKENS:
25 Resource Hubs (each with a unique symbol) — Residential Hubs — Flag Pieces

100 RESOURCE CARDS:
25 water, 25 transportation, 25 communication, 25 power

87 Event Cards
DICE

BOARD AREAS
Red Sector
Orange Sector
Yellow Sector

OBJECTIVE OF THE GAME

Earthquake is a cooperative game. You and your fellow players are members of a city council team, working together to create an earthquake resilient city. The objective is to build and maintain an inhabitable city that can recover from an earthquake by minimizing risk to your infrastructure. At the end of the game, the group with the most people points wins. Your city is near a fault line and an earthquake could strike at any time. Do you have what it takes to create a resilient and inhabitable city?

SETTING UP

1. Place the board in the center of the table within easy reach of all players. The hexagons on the board represent your city's preexisting infrastructure, consisting of basic potable water pipelines, dirt roads, power lines, and communication cables. This preexisting infrastructure is the bare minimum for your city's daily functioning.
2. Roll the die to determine who goes first. The highest role goes first. This player will be the **Mayor** for the game. The Mayor's job is to manage the board at the beginning of each round, outlined in the "Mayoral Checklist." The player to the left of the Mayor goes next. This player will be the **Architect**. The Architect's job is to record what and where resource tokens are placed on the board using the "Architect Record Sheet." The player to the left of the Architect is the **Earthquake Manager**. Using the "Earthquake Manager Record Sheet," The Earthquake Manager records if and how a hub reduces the level of damage an earthquake causes. Make sure everyone has their job sheets. Also make sure everyone has a "Game Guide" and a "Rulebook."
3. Separate the resource tokens by color (water = blue, transportation = black, communication = red, power = yellow) and place them near the board in four separate piles.
4. Shuffle the resource cards. The **Mayor** deals 2 resource cards to each player. The cards lay face-up.
5. The **Mayor** places 4 resource cards on the board in the **City Hall** section.

SETUP SUMMARY

1. **The Mayor hands each player 2 resource cards**
2. **The Mayor places on the board 4 resource cards in the City Hall section**
3. **Place the resource tokens within easy reach**
4. **Hand every player an "Earthquake Game Guide" and "Rulebook" for reference during the game**
5. **Place the resource card deck on the board in the spot labeled "RESOURCE CARDS"**
6. **Place the event card deck on the board in the spot labeled "EVENT CARDS"**
7. **Place the hub cards on the board in the spot labeled "HUB CARDS"**

A GAME TURN

Play proceeds clockwise around the table with each player taking turns in order. After each player takes a turn, one round has passed. At the beginning of each round, the **Mayor** performs round maintenance, referencing the "Mayoral Checklist" which explains what to do. The game continues until all event cards have been drawn or until the 1.5 hrs have passed. Each turn, the current player must:

1. **First draw an event card**
2. **Then draw either 1 resource card or 1 hub card. This choice is up to the player.**
3. **May take up to 2 actions**

After the player's turn is over, the player to the left takes their turn.

1. DRAWING CARDS A player's hand cannot exceed 5 cards.

EVENT CARDS. At the beginning of turns, players must draw 1 event card to add to their hand or to discard if not applicable. If a card is an **Earthquake** card, instead of taking the card in hand, refer to the **Rules of Earthquakes**, below.

The deck of event cards contains some cards that players may hold in their hands, some that must be played immediately, some that allows players to play immediately or discard, and some that may not be applicable to the board set-up. For example, if an event card is drawn that requires maintenance to a **Highway Hub**, but no such hub is on the board, ignore the event and discard. Each event card lists playing directions for that event card.

RESOURCE AND HUB CARDS. After an event card is drawn, players may draw either 1 resource card or 1 hub card, to hold in hand or to play on the board.

SHARING INFORMATION ABOUT CARDS. Players openly discuss strategies during the game. All cards in players' hands are face-up, for everyone to see. **Earthquake** is a cooperative game, and players work together as a city council team.

RULES OF EARTHQUAKES. When a player draws an **Earthquake** card, that player must immediately roll the die. The number rolled determines the damage level of the **Earthquake**, according to the chart below:

# on Die Roll	Resource Tokens Removed from Red Sectors (equal to dot #)	Resource Tokens Removed from Orange Sectors (dot # - 1)	Resource Tokens Removed from Yellow Sectors (dot # - 3)
6	6	5	3
5	5	4	2
4	4	3	1
3	3	2	none
2	2	1	none
1	1	none	none

At most risk of damage, the red sectors are on the fault line. At moderate risk, the orange sectors are near the fault line. The yellow sectors are furthest away from the fault line. Though still at risk for damage, yellow sectors undergo significantly less damage in the event of an **Earthquake**. The effect of an **Earthquake** diminishes at an increasing rate from the earthquake epicenter.

The above chart may be modified depending on the **Hubs** played on the board. Each hub has a unique function, many of which reduce the effect of an **Earthquake**. The **Earthquake Manager** records damage mitigation to help the group follow the **Earthquake Checklist**.

IN THE EVENT OF AN EARTHQUAKE, FOLLOW THE EARTHQUAKE CHECKLIST:

1) Roll to determine damage level. Reference above chart to determine **Earthquake** damage level.
2) Assess red sectors 1st:
    a. Account for any hubs on the board that mitigate damage for the red sectors
    b. Account for any red sector that mitigates damage for itself
    c. Remove the necessary number of accounted for tokens from each red sector. Players choose which tokens to remove
3) Repeat step 2 for orange sectors
4) Repeat step 2 for yellow sectors

After the appropriate number of resource tokens has been removed from the board, the player who drew the **Earthquake** card may continue their turn as normal.

CODE RED.

If a **Nuclear Power Plant** is on the board, the plant may go into **CODE RED** after an earthquake. If an earthquake takes either the **Nuclear Power Plant** and/or **Main Hub** offline, then the standard generators in the **Nuclear Power**

Plant are employed to cool the reactor core. If after 1 round has passed since an earthquake and both the **Nuclear Power Plant** and **Main Hub** are offline, these standard generators wear out and can no longer cool the reactor core. At this point, the **Nuclear Power Plant** is in **CODE RED**. With no generators working to cool the reactor core, you have 1 round to get both the **Nuclear Power Plant** and **Main Hub** back online before meltdown. Meltdown is when the reactor core melts through the containment vessel, exposing harmful radiation. The **Architect** is responsible for counting how many rounds the **Nuclear Power Plant** is non-functional and for managing **CODE RED**.

If the **Nuclear Power Plant** is upgraded with **Back-up Generators**, then **CODE RED** is delayed by 1 round. Thus with an upgrade, you have 2 rounds after an earthquake to get the **Nuclear Power Plant** and **Main Hub** back online before meltdown.

If meltdown occurs, the sector containing the **Nuclear Power Plant** becomes uninhabitable. For the rest of the game, nothing can be played on this sector. Remove all the tokens on this sector. These removed tokens are unusable for the rest of the game.

2. ACTIONS.

A player gets 2 actions to spend on their turn. A player may take 1 or no actions if they wish. Unused actions may not be saved from turn to turn.

Play a Resource Token

If a player has a resource card in their hand, they may discard that resource card to place that specific resource token (water, communications, power, or transportation) in a desired sector on the board as 1 action. If a resource card is available in **CITY HALL**, a player may discard this communal resource card to place that specific resource token in a desired sector on the board, which counts as 1 action. Refer to the rules for **Sector Construction and Expansion** about how resource tokens may be used to build a **Hub**.

Play a Hub Token

If a sector has the required resource tokens placed in that sector, a player may draw the desired hub card instead of drawing a resource card. As 1 action, this same player may place this hub's specific token in the middle of the chosen sector. Place this hub card in **HUB CENTRAL** on the board.

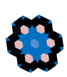
Upgrade a Hub

If a sector with a hub has the required resource tokens placed in that sector for a hub upgrade, a player may draw the desired upgrade hub card instead of drawing a resource card. As 1 action, this same player may flip over the hub token to the upgrade side. Place this upgrade hub card in **HUB CENTRAL** on the board.

SECTOR CONSTRUCTION AND EXPANSION

A sector consists of 7 hexagons put together. Sector perimeters are outlined on the board in a black flower shape. The middle hexagon of a sector is where a hub token may be placed. The outer 6 hexagons are where the required resource tokens may be placed. Any empty outer hexagon may be used to upgrade the existing hub, to provide reinforcement in preparation for an **Earthquake**, or may be left empty. **The 1st resource token to be placed in any sector must be a water token**. If a sector has a hub and all 4 resource tokens (water, transportation, communication, and power), players may expand out to an adjacent sector. A sector may not be played upon unless an adjacent sector has a hub and all 4 resource tokens.

ELEMENTS OF THE BOARD

MAIN HUB. 

Game play stars here. Your city's water supply of potable water is **Main Hub**, represented by the center sector with a solid blue middle hexagon. No hub should be placed in the middle hexagon, since this is already occupied by your city's water source. For your city to function, **Main Hub** must have one of each of the 4 resource tokens. You may not expand out to an adjacent sector without first occupying **Main Hub** with each of the 4 resource tokens. If at any time **Main Hub** is missing 1 of the 4 resource tokens, your city is non-functional and any other hubs placed on the board also become non-functional. To restore function to your city, **Main Hub** must have all 4 resource tokens in its sector.

HUB CENTRAL. As the game progresses, more hubs are built. When a hub token is played in a sector, the corresponding hub card is placed on the board in the area labeled "**HUB CENTRAL**." To help players organize a recovery plan in the event of an earthquake, **HUB CENTRAL** may be referenced to see what hubs require what resources to regain function.

CITY HALL. At the beginning of the game, 4 resource cards are placed face-up in the section on the board labeled "**CITY HALL**." These resource cards are communal and may be played as 1 action by any player on their turn. To play a **CITY HALL** resource card, all players must agree on how the card will be played. At the beginning of the game, players only have the original 4 resource cards in **CITY HALL**. If players decide to continue using **CITY HALL**, the **City Hall Hub** must be built on the board. If this hub is built, the **CITY HALL** resource cards may be replenished at the beginning of the round during which the hub was built. At the beginning of each subsequent round, the **Mayor** draws 1 resource card into **CITY HALL**.

GAME END

When all the event cards have been drawn or when the 1.5 hrs have passed, the game ends. You must now assess how inhabitable your city is based on the number of **Residential Hubs** are functioning on the board. Reference a **Residential Hub** card in **Hub Central** to determine which of your **Residential Hubs** meet the requirements of being functional. Count up the number of **People Points** you have. Each **Residential Hub** with a water token and a power token gives you **3 People Points**. Receive an additional **People Point** in this hub for a communication token. Receive an additional **People Point** in this hub for a transportation token. A **Residential Hub** can have a maximum of 5 **People Points**. For each **Residential Hub** one at a time, count up the number of **People Points**. Add together the **People Points** from all **Residential Hubs** on the board. The group with the most **People Points** wins!

EXAMPLE PLAY: ROUND MAINTENANCE AND 2 SAMPLE TURNS

WHERE THINGS STAND. Several rounds have passed and it is now the beginning of a new round.

ROUND MAINTENANCE. The **Mayor** first performs round maintenance before making their turn. 2 hubs are on the board, the **City Hall Hub** and a **Nuclear Power Plant Hub**. The unique characteristic of the **City Hall Hub** is that 1 resource card is added into the **CITY HALL** cards once a round. Accordingly, the **Mayor** draws 1 resource card and adds it to the **CITY HALL** cards.

The **Nuclear Power Plant Hub** generates 1 power token each round to be used by any player during that round. If a player has used this power token during the previous round, the **Mayor** replaces the power token by placing a new power token on top of the hub token for the **Nuclear Power Plant Hub**. This newly placed power token may be used by any player during the next round. If no player has used the power token generated by the power plant during the previous round, the **Mayor** may leave this sector as is.

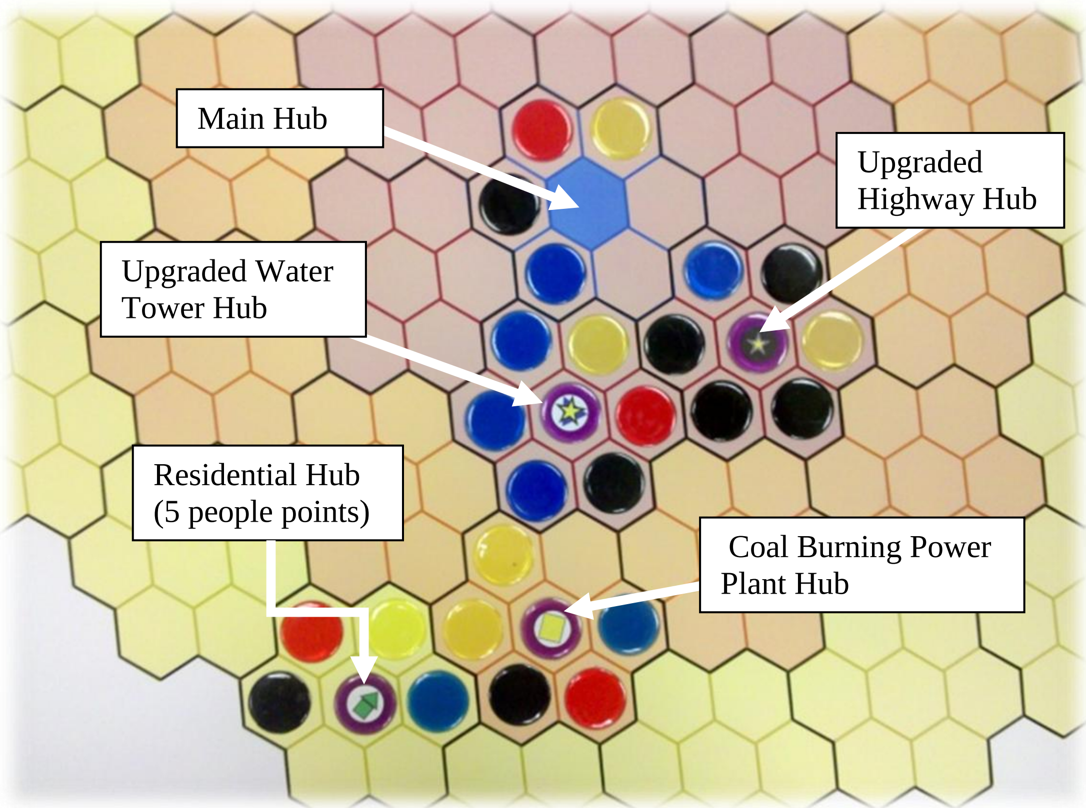
MAYOR TURN. As with all turns, the mayor first draws an event card. This event card drawn is a **Recycling Day** card. The mayor keeps this card in hand to play later. Because no sectors have enough resources to make a hub, the mayor decides to draw a card from the resource deck instead of selecting a hub card. The resource card drawn is a water.

On the board, there is 1 sector meeting most of the requirements for a **Fire Station Hub**. To build a **Fire Station Hub** in this sector, the group needs to place 2 water tokens in it. Through discussion, the group decides to make this sector a **Fire Station Hub** and creates a plan to do this. As 1 action, the mayor plays a water token in this sector. The water resource card is then discarded. The **Architect** records exactly in what hexagon the water token was placed on the "Architect Record Sheet." The mayor has no more water resource cards in their hand. Since **CITY HALL** does happen to have a water resource card, the group decides that the mayor may use this for the **Fire Station Hub**. As the second action, the mayor discards the water resource card from **CITY HALL** and places another water token in the sector of interest. The **Architect** records exactly in what hexagon this new water token was placed on the "Architect Record Sheet."

ARCHITECT TURN. The **Architect** 1st draws an event card. This event card is for coal maintenance. Since there is not a **Coal Power Plant Hub** on the board, the card is discarded. The **Architect** decides to draw a hub card instead of a resource card for their 2nd draw. Since a sector on the board meets all the requirements for a **Fire Station Hub**, the player draws this hub card and places it in **Hub Central**. As 1 action, the player then places the **Fire Station Hub Token** in the middle of this sector. The **Fire Station Hub** is now functioning. The **Earthquake Manager** records how the **Fire Station Hub** reduces earthquake damage level for the board on the "Earthquake Manager Record Sheet."

For the **Architect's** 2nd action, the player decides to reinforce another hub. The player notices that **Main Hub** only has 4 tokens in its sector and decides to reinforce **Main Hub** by placing an additional resource in this sector. Such resilience will minimize risk in the event of an earthquake. The resource card that the player happens to have in hand is a communication. The player discards this communication resource card and places a communication token in 1 of the empty hexagons in the **Main Hub** sector. The **Architect** then records where this communication token was placed in the "Architect Record Sheet."

AN EXAMPLE SET-UP



APPENDIX B

THE GAME GUIDE

WATER HUBS	FUNCTION	REQUIREMENTS
Fire Station	Reduces damage on the entire board by 1 level per sector	4 water
Fire Station Upgrade	Reduces total damage by 2 levels instead of 1 for this sector only	1 trans., 1 com.
Water Tower	Produces 1 water token per round	3 water, 1 power
Water Tower Upgrade	Reduces damage by 2 levels for the Water Tower sector	1 trans., 1 com.
Waste Treatment Plant	Allows removal of any amount of infrastructure -removing tokens from the board does not count as an action.	2 water, 1 power, 1 trans
Waste Treatment Plant Upgrade	Reduces damage by 2 levels for the Waste Treatment Plant sector	1 water, 1 trans.
POWER HUBS	**FUNCTION**	**REQUIREMENTS**
Coal Power Plant	Generates 1 power token per round	2 power, 1 trans, 1 water
Coal Power Upgrade	Reduces damage by 2 levels for the Coal Power Plant sector	1 trans.
Nuclear Power Plant	Generates 1 power token per round	2 power, 2 water, 1 com.
Nuclear Power Plant Upgrade	Delays CODE RED by 1 round (see rulebook)	1 power
Natural Gas Power Plant	Generates 1 power token per round	2 power, 1 trans., 1 com
Natural Gas Upgrade	Reduces damage by 2 levels for the Natural Gas Power Plant sector	1 trans.
COMMUNICATION HUBS	**FUNCTION**	**REQUIREMENTS**
City Hall	Reactivates City Hall	3 com., 1 water
City Hall Upgrade	Reduces damage by 1 level for the City Hall sector	1 power, 1 trans.
Radio and Cell Phone Tower	Generates 1 communication token per round	2 com., 1 power, 1 water
Radio and Cell Phone Tower Upgrade	Reduces damage by 2 levels for the Radio and Cell Phone Tower sector	1 trans., 1 com.
Emergency Response Systems	In the event of an earthquake, each player immediately draws 2 resource cards	2 com., 1 water,
Emergency Response Systems Upgrade	In the event of an earthquake, each player immediately draws 4 resource cards	1 com., 1 power, 1 trans.
TRANSPORTATION HUBS	**FUNCTION**	**REQUIREMENTS**
Highway	Reduces damage by 2 levels for this sector and adjacent sectors	3 trans., 1 water
Highway Upgrade	Increases range of Highway damage reduction effect by 1 sector radius	1 power, 1 trans.
Airport	Generates 1 transportation token per round	2 trans., 1 power, 1 com., 1 water
Airport Upgrade	Reduces damage by 2 levels for the Airport sector	1 trans.
Freight Trains	Allows exchange between tokens on the board -exchanges do not count as actions.	2 trans., 1 power, 1 com., 1 water
Freight Trains Upgrade	In the event of an earthquake, allows players to look through the next 4 cards in the resource deck and rearrange as desired.	1 trans.
WIN CONDITION HUB	**FUNCTION**	**REQUIREMENTS**
Residential	Gives 3 people points	1 water, 1 power
	Gives an additional people point	1 com.
	Gives an additional people point	1 trans.

TURN SEQUENCE:
1) Draw 1 event card
2) Draw 1 resource <u>or</u> 1 hub card
3) Take 2 actions

RULE REMINDERS:
* **THE 1ST RESOURCE TOKEN IN A SECTOR MUST BE A WATER TOKEN**
* **To expand from a sector, that sector must have 1 of each resource token (water, com., trans., power)**

HUB RATIO: For every 1 non-residential hub built on the board, you may build up to 2 residential hubs.

EARTHQUAKE CHECKLIST

1) Roll to determine magnitude. Earthquake effect is:
   a. the die roll for red sectors
   b. the die roll minus 1 for orange sectors
   c. the die roll minus 3 for yellow sectors
2) Assess red sectors 1st:
   a. Account for any hubs on the board that mitigate damage for the red sectors
   b. Account for any red sector that mitigates damage for itself
   c. Remove the necessary number of accounted for tokens from each red sector
3) Repeat step 2 for orange sectors
4) Repeat step 2 for yellow sectors

APPENDIX C

PLAYER ROLE SHEETS

The Mayoral Checklist

1) **If you have the City Hall hub functioning on the board:**
   Draw one resource card into a card spot on the board labeled "City Hall."

2) **If you have a Power Plant hub (Coal, Natural Gas, and/or Nuclear):**
   Place 1 power token on top of the power plant hub token. If the power token from the previous round was unused, simply leave that token where it is for anyone to use this next round.

3) **If you have a Water Tower hub:**
   Place 1 water token on top of the Water Tower hub token. If the water token from the previous round was unused, simply leave that token where it is for anyone to use this next round.

4) **If you have an Airport hub:**
   Place 1 transportation token on top of the Airport hub token. If the transportation token from the previous round was unused, simply leave that token where it is for anyone to use this next round.

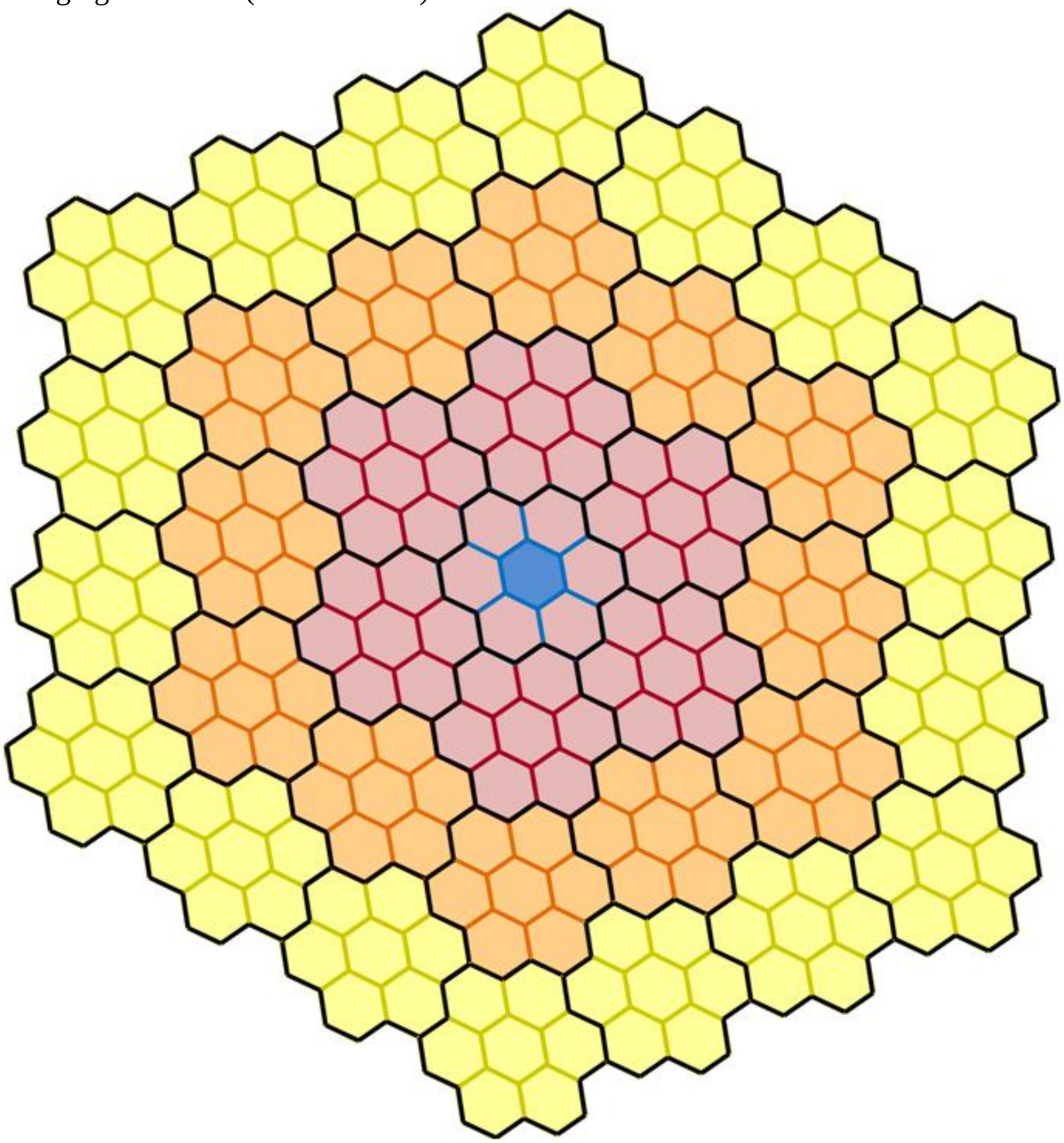
5) **If you have a Radio and Cell Phone Tower hub:**
   Place 1 communication token on top of the Radio and Cell Phone Tower hub token. If the communication token from the previous round was unused, simply leave that token where it is for anyone to use this next round.

6) Recap the past round with the other players in the game. On a separate sheet of paper, write down what you as a group want to build in the next couple rounds.

When finished, don't forget to take your turn!

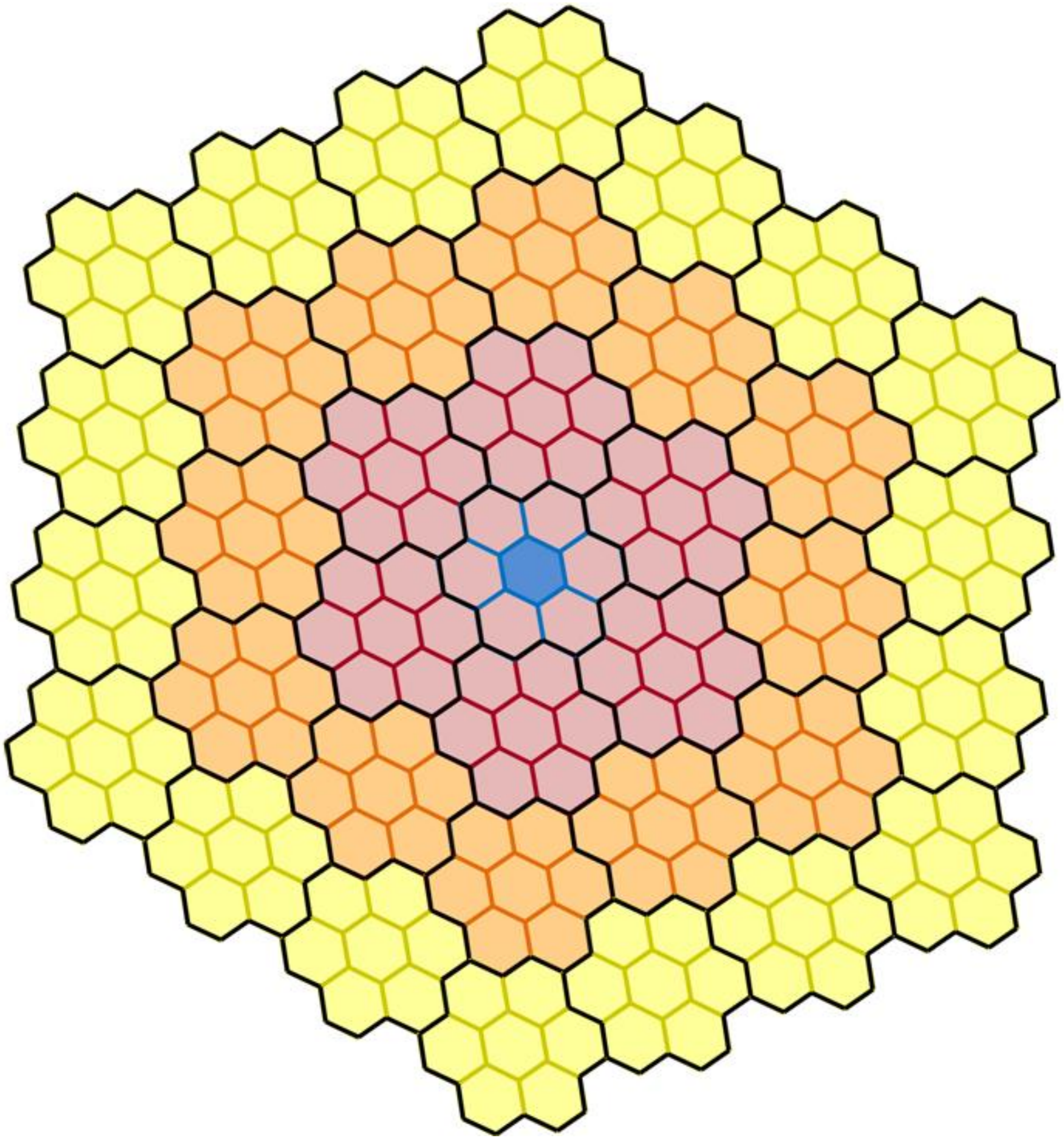
Architect Record Sheet (blank)

Record what types of resource tokens are in each sector with "W" for water, "T" for transportation, "C" for communication, and "P" for power. If a hub becomes non-functional, make sure to place a flag piece on that hub token on the actual board and to remove the flag when the hub becomes functional again. You are responsible for managing Code Red (see Rulebook).



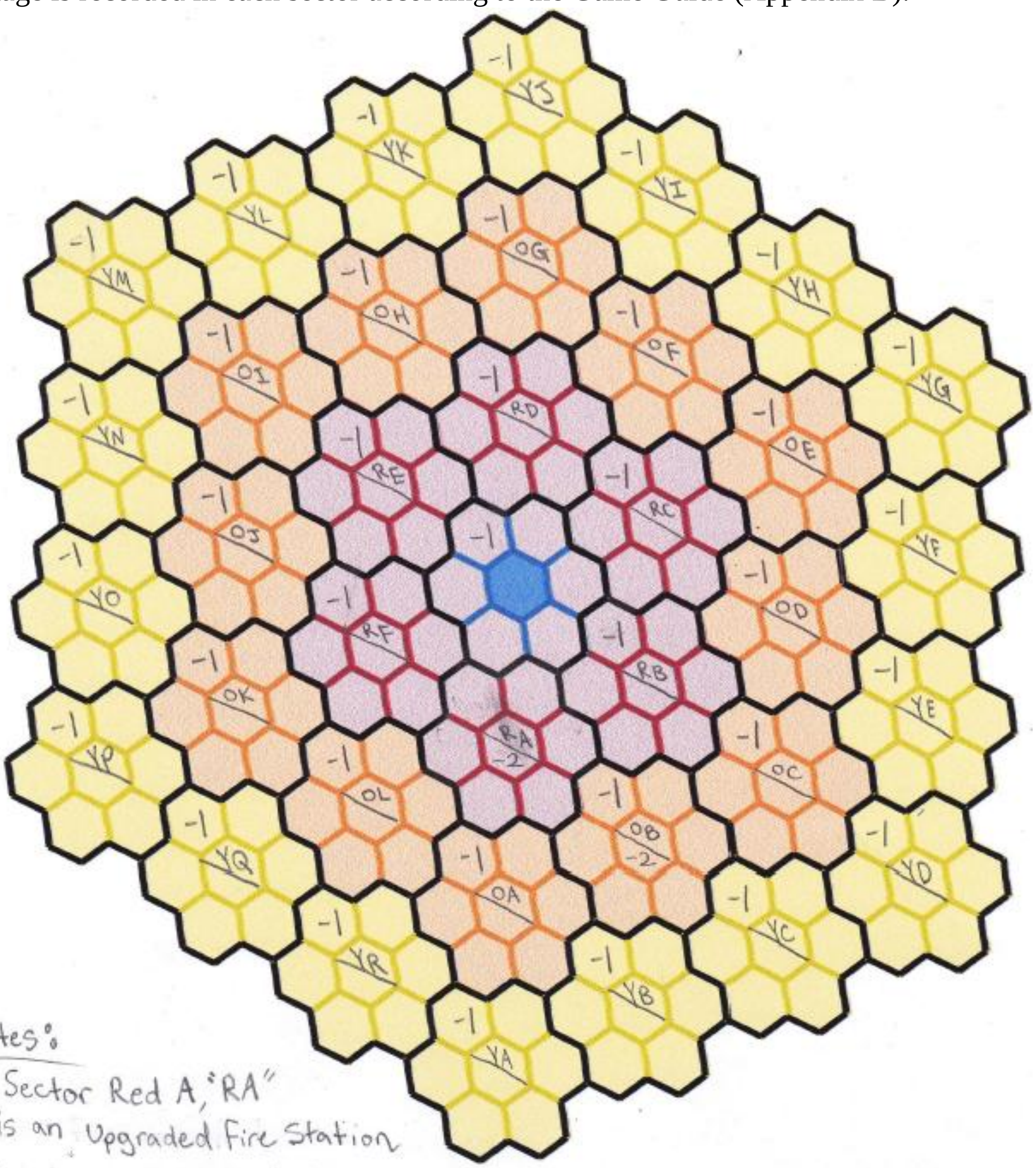
Earthquake Manager Record Sheet (blank)

Whenever a hub is built or upgraded, check your Game Guide. If that hub or upgrade reduces the damage level of an earthquake, record how so below. When an earthquake card is drawn, use your records to help your group go through the "Earthquake Checklist."



Earthquake Manager Record Sheet

Example Scenario: An Upgraded Fire Station (sector RA) and an Upgraded Natural Gas Plant (sector OB) are built on the board. How much they reduce the level of earthquake damage is recorded in each sector according to the Game Guide (Appendix B).

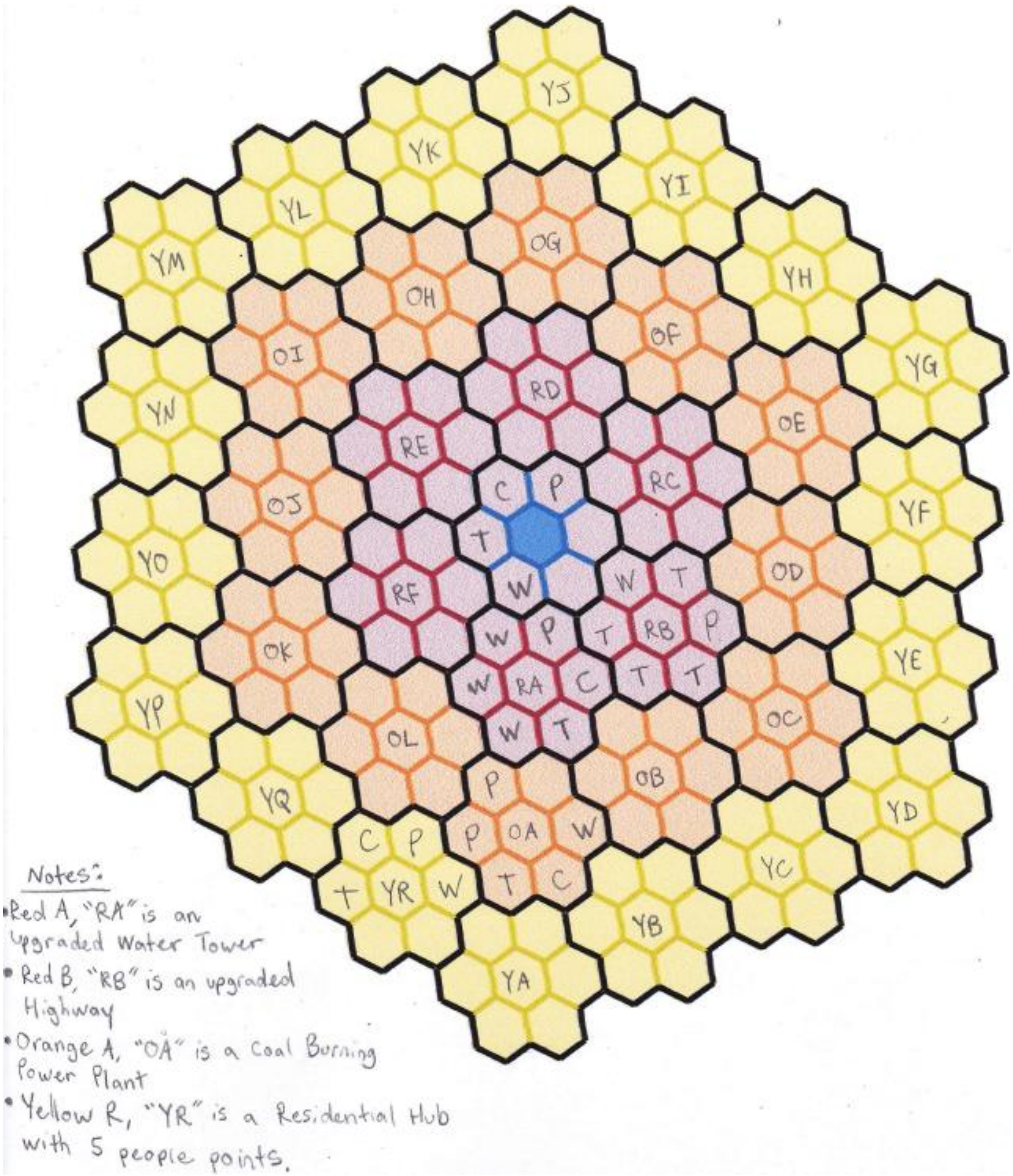


Notes:

- Sector Red A, "RA" is an Upgraded Fire Station
- Sector Orange B, "OB" is an Upgraded Natural Gas Power Plant

Architect Record Sheet

Different Example Scenario (for the picture shown on page 46 in the Rulebook): Built on the board are an Upgraded Water Tower (sector RA), and Upgraded Highway (sector RB), a Coal Burning Power Plant (sector OA), and a Residential Hub (sector YR).



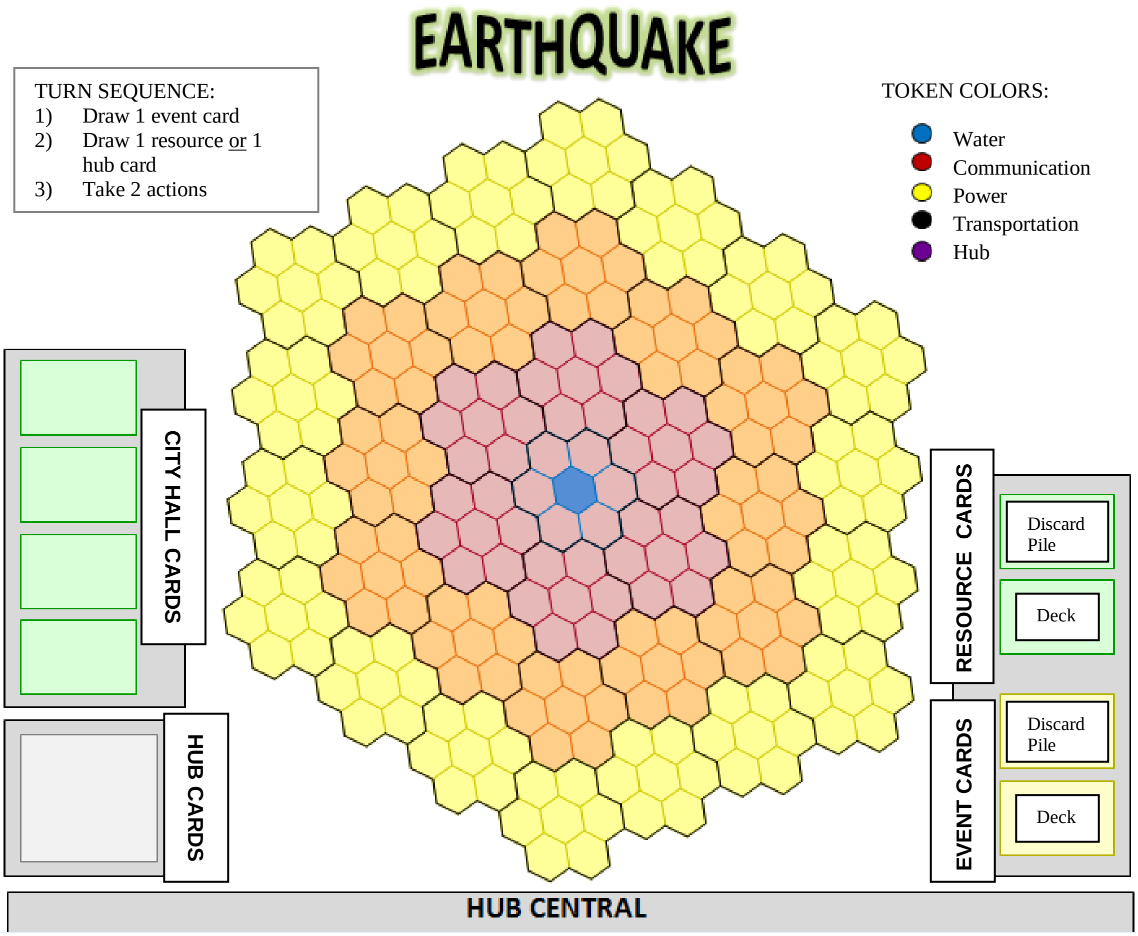
APPENDIX D

EXAMPLE EVENT CARD MODIFICATIONS

NUCLEAR POWER LOBBYISTS Roll a die, If 3 or lower: lobbyists oppose nuclear use, remove 1 power token from anywhere on board if possible. If 4 or higher: lobbyists support nuclear, receive 2 resource tokens of your choice to play on board.	**RESILIENCE REWARD** Resilient cities are more prone to surviving earthquakes. If there is more than one type of non-residential hub on the board, fill up the City Hall card slots with resource cards.	**RECYCLING DAY** Recycle your resource tokens! You may replace any token of your choice with any different kind of resource token of your choice. Counts as one action. Play now or keep in hand to play later.
BANK LOAN May borrow up to 2 resource tokens of your choice. Must be paid back by the beginning of your next turn. Any player may use resource tokens and/or cards to pay back loan. If loan is not paid on time, you must take twice the # of borrowed tokens off the board. May hold card in hand or discard.	**FIRE STATION FUNDRAISER** When played with the Fire Station hub card, receive a free water token to be played as a requirement to build the Fire Station. Player may hold card in hand or discard.	**ECONOMIC BOOM** The economy is thriving. Receive a free resource token of your choice to play now. Discard if unused.
RUSH HOUR TRAFFIC! If Highways hub is on the board, discard this card. If no Highway hub is on the board, citizens complain of persistent traffic jams. Remove 1 transportation token from the board, if possible.	**COAL PLANT MAINTENANCE** If no Coal Burning Power Plant is on the board, discard this card. If Coal Plant is on the board, there is a steam turbine oil leak. Remove 1 power token from anywhere on the board if possible.	**EARTHQUAKE!**

APPENDIX E

THE BOARD



APPENDIX F

GAME-BASED LEARNING CHECKLIST

Table F-1

Critical Thinking Category of the GBL Checklist

CRITICAL THINKING:	Scientific Argumentation:	Player A					Player B					Player C				
(C1) Raises a vital question or problem	Makes a claim (M)															
	Defends (D)															
	Clarifies (C)															
	Revises (R)															
	Asks for advice or ideas (A)															
	TOTAL															
(C2) Gathers and assess relevant information	Makes a claim															
	Defends															
	Clarifies															
	Revises															
	Asks for advice or ideas															
	TOTAL															
(C3) Comes to a well-reasoned solution	Makes a claim															
	Defends															
	Clarifies															
	Revises															
	Asks for advice or ideas															
	TOTAL															
(C4) Thinks open-mindedly within an alternative system of thought	Makes a claim															
	Defends															
	Clarifies															
	Revises															
	Asks for advice or ideas															
	TOTAL															

Table F-2

Metacognition Category of the GBL Checklist

METACOG-NITION (SELF-REGULATION AND CONTROL):	Scientific Argumentation:	Player A				Player B				Player C			
(M1) Plans by setting goals for playing and timing	Makes a claim (M)												
	Defends (D)												
	Clarifies (C)												
	Revises (R)												
	Asks for advice or ideas (A)												
	TOTAL												
(M2) Strategizes by deciding which strategy to use for a task or when to change a strategy	Makes a claim												
	Defends												
	Clarifies												
	Revises												
	Asks for advice/ideas												
	TOTAL												
(M3) Regulates time use, effort, pace, or performance	Makes a claim												
	Defends												
	Clarifies												
	Revises												
	Asks for advice/ideas												
	TOTAL												
(M4) Regulates motivation, emotion, or environment (volition control)	Makes a claim												
	Defends												
	Clarifies												
	Revises												
	Asks for advice/ideas												
	TOTAL												

Table F-3

Earthquake Engineering Content Knowledge Category of the GBL Checklist

EE CONTENT KNOWLEDGE:	Scientific Argumentation:	Player A	Player B	Player C
	Makes a claim (M)			
	Defends (D)			
	Clarifies (C)			
	Revises (R)			
	Asks (A)			
(E1) Inter-connectivity	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E2) Importance of water	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E3) Redundancy	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E4) Resilience	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E5) Human element	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E6) Safety	TOTAL			
	Makes a claim			
	Defends			
	Clarifies			
	Revises			
	Asks			
(E7) Real-life applications	TOTAL			

APPENDIX G

SAMPLE OF CODED TRANSCRIPTIONS FROM VIDEO-RECORDED STUDENT GAME-PLAY

B: So, remove one token from anywhere on the board. (Removes one of the two communication tokens from the right-side red sector).
A: (At the same time, points to the right-side red sector) Yea, do that.
C: Mmkay.
A: So now you (player c) get to put the transportation (token) out (onto the right-side red sector)?
B: (Draws resource card for player c).
A: Oh, right (player c needs to draw her cards before taking actions).
C: (Discards her event card and takes her resource card from player b).
B: You (player c) got a power.
C: (Discards her power resource card).
A: So, put it (player c’s power token) in that far one (left-side red sector that already contains a water token). Right? (Hands power token to player c)
C: (Places her power token in the left-side red sector that now contains a water and a power token).
B: (Updates Architect record sheet).
A: Yea.
C: Yea.
A: Okay so, you (player c) can play your transportation (resource card)
C: (Discards transportation resource card in hand).
B: I would play it (player c’s transportation token) here (points to the right-side red sector that contains a water, power, and communication token) so it
A: (Places player c’s transportation token in said sector) we can move off it. (This sector is now complete because it contains of each type of resource token; they players can now expand off this sector).
B: Yea.
A: (Draws event card). So it’s my turn and we have a water, we don’t have a Water Tower (hub). (Discards Water Leak event card).
B: Okay so (points to resource card deck).
A: Okay (draws resource card). So, I have water.
B: So, put it (player a’s water) here (points to a new orange sector that neighbors the complete right-side red sector).
A: (Places a water token in the new orange sector and discards her water resource card). Okay.
B: (Updates Architect record sheet).
A: So, now I’m done, right. So, what was our goal for that round?
B: Get to orange (zone). (Points towards the orange zone on the right-side of the board).
A: We’re already at orange (points to same area). So, we’ve done that. So, okay, we’ll build off that. (Updates goal sheet). And I’m done.
B: (Draws event card and does not read aloud; rolls die). Arg. Four (telling die to roll a four). Yes! (Throws hands in the air).
C: What?

- Player B’’ C3M, M2M, E3M
- Player A’’ C3D, M2D, E3D
- Player C’’ C3D
- A’’C3A, M2A
- A’’M3R
- B’’M3M
- A’’C3M
- A’’C3A, M3A
- C’’C3C
- A’’C3D
- C’’C3D
- A’’C2M
- B’’C3R
- A’’C3D, M2M,
- B’’C3D, M2D,
- A’’C2M, M3M
- B’’M3M
- A’’M3C
- B’’E2M
- B’’E6M
- B’’C3M, M2M
- A’’C3D
- A’’M3A
- A’’M1A
- B’’M1M, E6M
- A’’M1C
- A’’M1M, E6M
- A’’M3M
- B’’M4M
- C’’C2A, M4A

APPENDIX H

CRITICAL THINKING RESULTS OF GROUP 1 STUDENT GAME-PLAY

Table H-1

Group 1 Counts and Gains for the Critical Thinking Subcategory of Raises a Vital Question and/or Problem

Critical Thinking	Game 1			Game 2		
Raises a Vital Question or Problem	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	2	3	3	14	14	9
Defend	1	0	0	1	5	3
Clarify	2	2	0	0	3	7
Revise	0	2	2	3	1	0
Ask	6	19	6	18	8	4
Within Game Totals by Player	11	26	11	36	31	23
Between Game Gains by Player	25	5	12			

Table H-2

Group 1 Counts and Gains for the Critical Thinking Subcategory of Gathers and/or Assesses Relevant Information

Critical Thinking	Game 1			Game 2		
Gathers and/or Assesses Relevant Information	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	17	41	15	28	44	33
Defend	4	4	5	5	6	8
Clarify	10	10	14	24	22	25
Revise	3	11	2	3	11	9
Ask	24	22	12	27	25	6
Within Game Totals by Player	58	88	48	87	108	81
Between Game Gains by Player	29	20	33			

Table H-3

Group 1 Counts and Gains for the Critical Thinking Subcategory of Thinks Open-mindedly within an Alternative System of Thought

Critical Thinking	Game 1			Game 2		
Thinks Open-mindedly within an Alternative System of Thought	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	2	3	2	8	3	8
Defend	0	2	2	1	1	0
Clarify	0	0	0	1	0	0
Revise	0	0	0	0	0	1
Ask	0	4	1	3	6	2
Within Game Totals by Player	2	9	5	13	10	11
Between Game Gains by Player	11	1	6			

APPENDIX I

CRITICAL THINKING RESULTS OF GROUP 2 STUDENT GAME-PLAY

Table I-1

Group 2 Counts and Gains for the Critical Thinking Subcategory of Raises a Vital Question and/or Problem

Critical Thinking	Game 1			Game 2		
Raises a Vital Question or Problem	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	6	8	3	18	16	4
Defend	3	0	0	1	1	2
Clarify	3	0	0	4	3	1
Revise	0	0	0	0	2	1
Ask	6	8	6	12	8	4
Within Game Totals by Player	18	16	9	35	30	12
Between Game Gains by Player	17	14	3			

Table I-2

Group 2 Counts and Gains for the Critical Thinking Subcategory of Comes to a Well-reasoned Solution

Critical Thinking	Game 1			Game 2		
Comes to a well-reasoned solution	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	33	21	11	51	38	9
Defend	18	16	10	25	28	22
Clarify	22	14	6	56	37	21
Revise	4	5	3	10	17	5
Ask	6	8	1	23	16	2
Within Game Totals by Player	83	64	31	165	136	59
Between Game Gains by Player	82	72	28			

Table I-3

Group 2 Counts and Gains for the Critical Thinking Subcategory of Thinks Open-mindedly within an Alternative System of Thought

Critical Thinking	Game 1			Game 2		
Thinks Open-mindedly within an Alternative System of Thought	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	10	9	2	11	11	4
Defend	1	5	1	3	2	0
Clarify	3	2	0	2	2	1
Revise	0	0	0	3	1	0
Ask	1	6	2	4	8	2
Within Game Totals by Player	15	22	5	23	24	7
Between Game Gains by Player	8	2	2			

APPENDIX J

METACOGNITION RESULTS OF GROUP 1 STUDENT GAME-PLAY

Table J-1

Group 1 Counts and Gains for the Metacognition Subcategory of Plans by Setting Goals for Playing and Timing

Metacognition	Game 1			Game 2		
Plans by Setting Goals for Playing and Timing	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	0	6	3	15	16	14
Defend	3	5	1	5	5	3
Clarify	2	6	2	7	7	10
Revise	0	1	0	1	3	6
Ask	2	7	1	8	11	3
Within Game Totals by Player	7	25	7	36	42	36
Between Game Gains by Player	29	17	29			

Table J-2

Group 1 Counts and Gains for the Metacognition Sub-category of Strategizes by Deciding which Strategy to Use for a Task or When to Change a Strategy

Metacognition	Game 1			Game 2		
Strategizes by Deciding which Strategy to Use for a Task or When to Change a Strategy	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	11	18	7	36	28	26
Defend	9	10	10	16	10	18
Clarify	5	10	8	18	8	12
Revise	4	5	6	9	11	7
Ask	8	8	8	17	13	7
Within Game Totals by Player	37	51	39	96	70	70
Between Game Gains by Player	59	19	31			

Table J-3

Group 1 Counts and Gains for the Metacognition Subcategory of Regulates Motivation, Emotions, or Environment

Metacognition	Game 1			Game 2		
Regulates Motivation, Emotions, or Environment	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	12	19	16	37	23	21
Defend	0	0	1	1	3	4
Clarify	4	6	2	6	3	5
Revise	0	1	0	0	0	0
Ask	2	2	1	1	3	2
Within Game Totals by Player	18	28	20	45	32	32
Between Game Gains by Player	27	4	12			

APPENDIX K

METACOGNITION RESULTS OF GROUP 2 STUDENT GAME-PLAY

Table K-1

Group 2 Counts and Gains for the Metacognition Subcategory of Plans by Setting Goals for Playing and Timing

Metacognition	Game 1			Game 2		
Plans by Setting Goals for Playing and Timing	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	9	13	3	29	25	12
Defend	4	6	11	14	14	6
Clarify	16	9	2	19	13	4
Revise	1	4	1	6	3	2
Ask	11	10	1	18	16	2
Within Game Totals by Player	41	42	18	86	71	26
Between Game Gains by Player	45	29	8			

Table K-2

Group 2 Counts and Gains for the Metacognition Sub-category of Strategizes by Deciding which Strategy to Use for a Task or When to Change a Strategy

Metacognition	Game 1			Game 2		
Strategizes by Deciding which Strategy to Use for a Task or When to Change a Strategy	Player 2A	Player 12B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	27	33	10	48	35	16
Defend	17	18	6	18	28	19
Clarify	10	9	3	41	16	15
Revise	7	5	1	16	21	6
Ask	6	11	6	27	17	1
Within Game Totals by Player	67	76	26	150	117	57
Between Game Gains by Player	83	41	31			

Table K-3

Group 2 Counts and Gains for the Metacognition Subcategory of Regulates Motivation, Emotions, or Environment

Metacognition	Game 1			Game 2		
Regulates Motivation, Emotions, or Environment	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	11	28	8	17	16	4
Defend	2	1	1	3	3	3
Clarify	1	9	4	1	4	6
Revise	0	1	0	1	1	1
Ask	2	4	2	0	3	2
Within Game Totals by Player	16	43	15	22	27	16
Between Game Gains by Player	6	-16	1			

APPENDIX L

EARTHQUAKE ENGINEERING CONTENT KNOWLEDGE RESULTS FOR GROUP 1 STUDENT GAME-PLAY

Table L-1

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of the Interconnectivity

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Interconnectivity	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	2	2	0	5	3	5
Defend	2	0	1	1	1	1
Clarify	0	1	1	1	0	1
Revise	0	0	0	0	0	0
Ask	0	0	0	3	1	0
Within Game Totals by Player	4	3	2	10	5	7
Between Game Gains by Player	6	2	5			

Table L-2

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Importance of Water

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Importance of Water	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	0	0	0	4	3	4
Defend	0	0	0	0	1	1
Clarify	0	0	0	1	2	0
Revise	0	0	0	0	0	0
Ask	0	0	0	0	0	0
Within Game Totals by Player	0	0	0	5	6	5
Between Game Gains by Player	5	6	5			

Table L-3

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Redundancy

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Redundancy	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	1	3	1	2	1	0
Defend	4	3	1	1	1	0
Clarify	0	1	2	0	0	1
Revise	0	0	0	0	0	0
Ask	1	1	1	0	0	0
Within Game Totals by Player	6	8	5	3	2	1
Between Game Gains by Player	-3	-6	-4			

Table L-4

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Resilience

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Resilience	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	2	0	0	6	2	7
Defend	0	0	0	0	3	3
Clarify	1	0	0	0	0	0
Revise	0	0	0	0	0	0
Ask	0	0	0	1	0	0
Within Game Totals by Player	3	0	0	7	5	10
Between Game Gains by Player	4	5	10			

Table L-5

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of the Human Element

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Human Element	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	0	1	0	1	6	0
Defend	0	0	0	0	2	0
Clarify	1	2	1	3	1	1
Revise	0	0	0	0	0	0
Ask	1	3	0	0	0	1
Within Game Totals by Player	2	6	1	4	9	2
Between Game Gains by Player	2	3	6			

Table L-6

Group 1 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Real-Life Application

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Real-Life Application	Player 1A	Player 1B	Player 1C	Player 1A	Player 1B	Player 1C
Claim	0	0	0	1	2	0
Defend	0	0	0	0	0	1
Clarify	0	0	0	0	0	0
Revise	0	0	0	0	0	0
Ask	0	0	0	0	0	0
Within Game Totals by Player	0	0	0	1	2	1
Between Game Gains by Player	1	2	1			

APPENDIX M

EARTHQUAKE ENGINEERING CONTENT KNOWLEDGE RESULTS FOR GROUP 2 STUDENT GAME-PLAY

Table M-1

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Interconnectivity

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Interconnectivity	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	7	1	0	10	13	2
Defend	7	4	3	3	5	1
Clarify	4	2	1	9	6	1
Revise	0	0	0	1	0	0
Ask	1	0	0	3	3	0
Within Game Totals by Player	19	7	4	26	27	4
Between Game Gains by Player	7	20	0			

Table M-2

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Importance of Water

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Importance of Water	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	1	9	1	10	5	1
Defend	1	2	2	1	3	2
Clarify	0	3	0	1	3	1
Revise	0	0	0	0	1	0
Ask	0	0	1	3	2	0
Within Game Totals by Player	2	14	4	15	14	4
Between Game Gains by Player	13	0	0			

Table M-3

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Redundancy

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Redundancy	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	1	7	0	7	4	1
Defend	2	3	0	4	3	3
Clarify	1	1	0	4	2	1
Revise	0	0	0	0	0	0
Ask	1	2	1	2	1	0
Within Game Totals by Player	5	13	1	17	10	5
Between Game Gains by Player	12	-3	4			

Table M-4

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Resilience

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Resilience	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	5	3	0	8	16	2
Defend	2	1	0	1	7	3
Clarify	1	2	0	7	5	3
Revise	0	0	0	1	1	0
Ask	0	0	0	1	2	0
Within Game Totals by Player	8	6	0	18	31	8
Between Game Gains by Player	10	25	8			

Table M-5

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Safety

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Safety	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	4	4	1	7	10	4
Defend	3	0	2	4	4	4
Clarify	3	4	1	6	6	0
Revise	1	1	0	1	0	0
Ask	1	0	0	0	0	0
Within Game Totals by Player	12	9	4	18	20	8
Between Game Gains by Player	6	11	4			

Table M-6

Group 2 Counts and Gains for the Earthquake Engineering Content Knowledge Subcategory of Real-life Application

Earthquake Engineering Content Knowledge	Game 1			Game 2		
Real -life Application	Player 2A	Player 2B	Player 2C	Player 2A	Player 2B	Player 2C
Claim	0	0	0	5	1	1
Defend	0	0	0	2	2	4
Clarify	0	0	0	0	0	0
Revise	0	0	0	0	0	1
Ask	0	0	0	0	0	0
Within Game Totals by Player	0	0	0	7	3	6
Between Game Gains by Player	7	3	6			

APPENDIX N

CURRICULUM VITA

Last updated May, 2016

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PROFESSIONAL INTERESTS

Game-based learning, Game research and development, Play theory, Social learning, Physics, Science education, Statistics

EDUCATION

Ph.D. Candidate	Curriculum and Instruction
Focus:	Science Education
2011- Current	Texas A&M University, College Station, Texas
M.S.	Physics
Focus:	Condensed Matter Theory
2009	Ball State University, Muncie, Indiana
B.S.	Physics
Minor:	Mathematics
2007	Ball State University, Muncie, Indiana

EMPLOYMENT HISTORY

2014-current	Texas A&M University. Graduate Research Assistant, Game-based learning, Texas Transportation Institute
2013-2014	Texas A&M University. Graduate Research Assistant, Center for Mathematics and Science Education, College of Science
2012	Texas A&M University. Graduate Teaching Assistant, Department of Teaching, Learning and Culture
2011-2012	Texas A&M University. Graduate Research Assistant, Earthquake Engineering Education Project workshop coordinator, Department of Teaching, Learning and Culture
2010	Blinn College. Physics Instructor, Department of Natural Sciences
2007-2009	Ball State University. Physics Graduate Teaching Assistant, Department of Physics and Astronomy

PUBLICATIONS

Perkins, A., Stuessy, C., & Fry, G. (2016, June). *Earthquake engineering education and game-based learning: A research and development methodology for a collaborative-competitive board game.* Paper proceeding at the American Society for Engineering Education Annual Conference and Exposition (accepted).

Perkins, A. (2011). *Electron spin-polarization via nano-electronic circuits* (master's thesis). Hedin, E. & Joe, Y. as contributing researchers. Saarbrücken, Germany: Lambert Academic Publishing.

Hedin, E., Perkins, A., & Joe, Y. (2011). Combined Aharonov-Bohm and Zeeman spin-polarization effects in a double quantum dot ring. *Physics Letters A, 375*(3), 651-656.

RESEARCH

2011-2016	Educational game research and development, dissertation, Texas A&M University
2014-2016	Curriculum development, K-12 game-based learning progression about civil engineering, Texas Transportation Institute, Texas A&M University
2013-2014	Evaluator, co-coordinator; AggieTEACH Teacher Preparation Academy, Texas A&M University
2013	Science education and classroom evaluation, Biological Society of America, Texas A&M University
2012	STEM teacher professional development, the Earthquake Engineering Education Project, Texas A&M University
2011	Science and energy engineering education, Live Energy Project, Texas A&M University
2007-2009	Nano-electronic circuits, thesis, Ball State University
2007	Theoretical physics research, Quantum Computation, Ball State University
2006	Observational astronomy research, Ball State University

AWARDS AND CERTIFICATIONS

2012, 2015	Graduate Research Grant, College of Education and Human Development, Texas A&M University

2012, 2015 Graduate Travel Grant, College of Education and Human Development, Texas A&M University

2012 Certification in Applied Statistics, Department of Statistics, Texas A&M University

2011 Lehner Scholar, Texas A&M University, Department of Teaching, Learning, and Culture

2007 Research symposium winner, *Quantum Computing*, Ball State University

PROFESSIONAL CONFERENCES

Perkins, A., Stuessy, C., & Fry, G. (2016, June). *Earthquake engineering education and game-based learning: A research and development methodology for a collaborative-competitive board game.* Presentation at the American Society for Engineering Education Annual Conference and Exposition, New Orleans, LA (accepted).

Perkins, A., & Stuessy, C. (2015, October). *Beyond engagement: Inductive evaluation of a 21st century educational board game.* Presentation at the National School Science and Mathematics Association, Oklahoma, OK.

Perkins, A., & Stuessy, C. (2015, April). *The earthquake engineering game: Synthesizing instruction and game design for 21st century science learning*. Presentation at the National Association for Research in Science Teaching, Chicago, IL.

Perkins, A. (2015, March). Attendee at the Annual Game Developers Conference, San Francisco, CA.

Perkins, A., & Stuessy, C. (2014, April). *Social discourse patterns: When scientists partner with students online.* Presentation at the National Association for Research in Science Teaching, Pittsburgh, PA.

Perkins, A., & Scott, T. (2014, March). *A STEM teacher preparation program: Where scientific and technological literacy meet.* Presentation at the National Association for Research in Science Teaching, Pittsburgh, PA.

Perkins, A., & Stuessy, C. (2013, November). *A gaming innovation engaging students in the STEM domains of earthquake engineering.* Presentation at the National School Science and Mathematics Association, San Antonio, TX.

Perkins, A., Whitfield, J., Parker, D., Schroeder, C., & Wilding, L. (2013, November). *TPACK analysis of a STEM teacher prep academy.* Presentation at the Center for Research, Evaluation and Advancement of Teacher Education, Quest for Quality: Excellence in Teacher Preparation & Research in Teaching, Austin, TX.

Perkins, A., & Stuessy, C. (2013, April). *Earthquake: An educational innovation engaging students in the STEM domains of earthquake engineering.* Presentation at the National Association for Research in Science Teaching, San Juan, Puerto Rico.

Perkins, A., & Stuessy, C. (2012, November). *Earthquake engineering education project: A classroom board game for high school students.* Presentation at the School Science and Math Association, Birmingham, AL.

Perkins, A. & Stuessy, C. (2011, November). *Introducing engineering into Texas state math and science curricula.* Presentation at the School Science and Math Association, Colorado Springs, CO.

Perkins, A., Hedin, E., & Joe, Y. (2009, April). *Combined Zeeman and Aharonov-Bohm effects in a double quantum dot ring*. Presentation at the Ohio Section American Physical Society, Akron, OH.

Perkins, A., Hedin, E., & Joe, Y. (2009, October). *Electron spin polarization via Zeeman and Aharonov-Bohm effects in a double quantum dot ring*. Presentation at the Indiana Academy of Science 125th Meeting, Kokomo, IN.

Perkins, A., & Hedin, E. (2006, November). *Quantum Computing: Principles and Possibilities*. Presentation at the Indiana Academy of Science 121st Meeting, Muncie, IN