THE INTERACTION EFFECTS OF WORKING MEMORY CAPACITY, GAMING EXPERTISE, AND SCAFFOLDING DESIGN ON ATTENTION AND COMPREHENSION IN DIGITAL GAME BASED LEARNING

By

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ABSTRACT

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Educational digital games are often complex problem-solving experiences that can facilitate systematic comprehension. However, empirical studies of digital game based learning (DGBL) have found mixed results regarding DGBL's effect in improving comprehension. While learners generally enjoyed the DGBL learning experience, they often failed to comprehend the underlying message and construct knowledge. One possible explanation for the mixed results is that DGBL comprehension is moderated by individual differences in working memory and gaming expertise (knowledge, skills). Due to the procedural nature of communication in game design, learning from digital games requires processing multiple interacting elements within one's working memory. The amount of available working memory that can be allocated to processing the *educational* messages is affected by the learner's expertise about the game mechanics, along with the structure of the game design.

This study seeks to investigate how working memory capacity and gaming skill expertise interact with game scaffolding design to influence attention and comprehension. Two specific game scaffolding designs—*content-knowledge scaffolding* and *gaming-skill scaffolding* are examined in this study. The two designs are aimed to support learning by reducing the amount of efforts that players need to exert to figure out how to play the game, thus reducing the demand on their working memory and freeing up working memory for comprehension. But some studies

have shown that learners' expertise level also moderates the effect of these designs. Learners with more expertise do not benefit from scaffolding--a phenomenon known as *expertise-reversal effect* or *reverse cohesion effect*.

This study has three goals: (1) to examine the influence of individual working memory capacity and gaming expertise on attention and comprehension in the context of digital games; (2) to examine the effect of scaffolding designs on attention and comprehension with regards to working memory and expertise; and (3) to examine competing explanations from the expertise-reversal effect and the reverse-cohesion effect.

The findings showed that gaming expertise significantly predicts attention when the player can recognize the game design (the game mechanics) as within their gaming expertise domain. Consistent with the expertise reversal effect and the reverse cohesion effect, players with higher gaming-skill expertise paid more attention to the gaming-skill scaffolding design. However, the findings suggest that gaming-skill experts and non-experts focused their attention on different aspects of the game. Working memory capacity and attention only predicted comprehension for learners with lower gaming-skill expertise. Working memory capacity and attention did not predict comprehension for learners with higher gaming-skill expertise. The gaming-skill scaffolding design was effective in mitigating the gap between learners with high and low gaming-skill expertise. However the content-knowledge scaffolding widened the gap between learners with relative high and low prior content knowledge. The study argues that skill-based scaffolding can improve comprehension for non-experts in the context of digital game based learning. But whether scaffolding helps or harms comprehension for gaming experts depends on if the design activates retrieval of expert mental models and whether the game's narrative is closely aligned with its underlying messages.

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Chapter 1

Introduction

How does working memory capacity affect attention and learning from educational digital games? Do expert gamers comprehend more of the educational message than novice gamers when learning via digital games? And how do working memory capacity and gaming skill expertise interact with game scaffolding designs to affect attention and learning? These are the three main research questions that this dissertation seeks to investigate.

An increasing number of digital games are designed and used for educational purposes (e.g., Barab et al., 2007; Peng, 2009; Squire, 2003). These digital games are used in a wide range of fields including school education (Barab et al., 2007; Kiili, 2005; Papastergiou, 2009), professional training (Edery & Mollick, 2009; Hays, Jacobs, Prince, & Salas, 1992; McDowell, Darkin, Sullivan, & Johnson, 2006; Michael & Chen, 2006), and health promotion (Peng, 2009), including medical treatment and rehabilitations (Kato, Cole, Bradlyn, & Pollock, 2009). It is estimated that more than $125 million is invested into developing educational games every year (Blunt, 2007).

Many scholars have argued that digital games are an ideal media for communicating systematic knowledge and preparing learners for solving real-life problems (e.g., Gee, 2007; Squire, 2003). However, despite the enthusiasm for digital game-based learning (DGBL) among scholars and education practitioners, empirical research has found mixed results regarding digital games' effectiveness in improving knowledge comprehension and problem-solving transfer (Foster & Mishra, 2009; Hays, 2005; Kirriemuir & McFarlane, 2004; Mitchell & Savill-Smith, 2004; Randel, Morris, Wetzel, & Whitehill, 1992). A common finding is that although learners preferred digital games over traditional classroom instructional methods, learners often have difficulties understanding the underlying messages and fall short on constructing systematic mental model of the relationships communicated through the games (Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005). Why do some learners fail to comprehend the underlying message from digital game based learning? A potential explanation that has not been fully examined is that digital game based learning design may overload learners' limited working memory capacity; working memory capacity that is known to predict learners' performance in complex cognitive tasks (Yuan, Steedle, Shavelson, Alonzo, & Oppezzo, 2006)).

Working memory is a conceptual workspace in the human mind where selected information from environmental stimuli (e.g., auditory, visual) and information from long-term memory are temporarily stored for cognitive processing. (Baddeley, 1992, 2000, 2007; Logie, 2011). An individual's working memory capacity has been shown to be correlated with performance in complex cognitive tasks such as learning, reasoning, comprehension, and problem-solving (Kyllonen & Christal, 1990; Yuan et al., 2006). Cognitive psychologists generally agree that individuals have a limited working memory capacity and that different cognitive tasks demand different amount of working memory. When a task exceeds one's working memory capacity, the individual cannot sustain his/her attention or process any more information (Baddeley, 1992; Cowan, 2008; Kane & Engle, 2003; Lang, 2006).

Educational games are complex problem-solving tasks that require a wide range of cognitive processing such as visual-spatial navigation, perceptual motor skills, accurate timing of responses, as well as short and long-term strategic decisions (Logie, Baddeley, Mane, Donchin, & Sheptak, 1989). As a complex problem-solving task, digital games often require learners to simultaneously hold multiple interacting elements (e.g., goals, controls, and available resources) in their limited working memory (Grodal, 2000), which demands large amount of working memory capacity from the learners. In addition to holding the multiple elements in ones' working memory, digital games require active decision making and inputs from learners for the narrative to develop, and understanding of the narrative is a prerequisite for understanding the educational messages (Fisch, 2000).Under the structure of digital games, a portion of the learners' working memory is required to process the game mechanics and narratives first, and the remaining available working memory is then used for processing information related to the educational content.

With regards to people's limited working memory capacity, educational games face a dilemma. On the one hand, digital games are believed to facilitate systematic comprehension by encouraging learners to explore different identities and solutions in dynamic simulated environments (Shaffer, Squire, Halverson & Gee, 2005; Squire, 2003). On the other hand, the working memory demands from its interactive narrative structure and simultaneously processing the multiple interacting elements may leave learners with insufficient working memory to process the educational messages, which may result in poor comprehension (Scheiter & Gerjets, 2007). The first goal of this study seeks to investigate how working memory capacity affects comprehension of educational content in an educational game.

Asides from working memory, domain expertise is also a strong predictor of performance on cognitive tasks. Studies have shown that domain experts are able to simultaneously maintain a large amount of information specific to their expertise domain (Ericsson & Kintsch, 1995). Experts are also less susceptible to disruption and distraction (Kane & Engle, 2003), and are more capable of recalling previous experiences in their expertise domain (Chase & Ericsson, 1982; Ericsson & Delaney, 1998). Such improved performance is often attributed to experts' ability to "chunk" related information rather than process individual elements independently

(Ericsson & Delaney, 1998; Miller, 1956). With extensive practice, experts may be able to process chunks of information automatically, further reducing the amount of working memory required to perform a task. The second goal of this study seeks to investigate how gaming expertise influences available working memory and comprehension of educational content communicated in an educational game.

If comprehension is solely determined by individual characteristics such as working memory capacity and expertise, one would predict that learners with higher working memory capacity and more expertise will consistently comprehend more of the educational content than learners with lower working memory capacity and expertise. However, studies of instructional design found that experts do not always learn more than novices. Several studies have observed that instructional designs which seek to reduce working memory demands may unintentionally hurt expert learners' comprehension, a phenomenon with two competing theoretical explanations: the *expertise-reversal effect* (Kalyuga, Ayres, Chandler, & Sweller, 2003; Kalyuga, Chandler, & Sweller, 2000) and the *reverse-cohesion effect* (McNamara, Kintsch, Songer, & Kintsch, 1996).

The expertise-reversal effect argues that because experts are capable of processing the tasks using their prior schema and mental models, the additional instructional information in a tutorial introduces redundant working memory demands that are unnecessary, but unavoidable for expert learners, leading to worse comprehension (Kalyuga et al. 2000; Yeung, Jin, and Sweller, 1998). The reverse-cohesion effect argues that by reducing the demand on working memory through scaffolding, experts a false sense of understand and thus cause them to process the information superficially, consequently missing out on important information. In other words, McNamara et al. (1996) argues that more demanding media design (not scaffolded by tutorials or other means) helps experts learn because it forces them to actively use their expertise to process the information; however more demanding media hurts novices because they do not have the expertise to process the information. The third goal of this study is to investigate how working memory capacity and gaming expertise interact with different scaffolding designs to affect attention and comprehension.

Theoretical and Practical Contributions

This dissertation is expected to contribute to scientific understanding of how individual differences (i.e. working memory capacity, gaming expertise) interact with media design to influence available working memory and comprehension from digital game based learning. While several studies have suggested that learners' working memory capacity may influence learning outcomes in DGBL (Grodal, 2000; Kiili, 2005; Vorderer, 2000), few studies have empirically examined this relationship. It is also important to understand how gaming expertise affects available working memory and comprehension because educational games are often assigned as educational tools or assessments. When games are assigned as educational tools or assessments, all learners regardless of their gaming expertise must learn from the game. Understanding the learning impact of crucial individual differences (working memory capacity and gaming expertise) can help educational game designers and educators work to optimize DGBL for all learners.

To summarize, this study has three goals: (1) to examine the influence of individual working memory capacity in digital game based learning; (2) to examine the effect of gaming-skill expertise on available working memory and comprehension; and (3) to examine the expertise-reversal effect and reverse-cohesion effect in the context of digital game based learning.

Chapter 2

Digital Game Based Learning and Working Memory Capacity

The first goal of this study is to investigate how individuals' working memory capacity affects comprehension in digital game based learning. This chapter will begin with a brief review of digital game based learning and how working memory is involved in the process of learning with digital games. Next, the chapter will review the current understanding and conceptualization of working memory, focusing on the individual difference approach (e.g., Cowan, 2005; Engle, Kane, & Tuholski, 1999) to guide development of hypotheses on how working memory capacity may influence attention and comprehension from DGBL. The second goal of this study seeks to investigate how gaming expertise influences attention and comprehension. Therefore the second half of this chapter will discuss the relationship between expertise and working memory capacity on complex cognitive tasks.

Digital Game Based Learning and Working Memory

Digital game based learning (DGBL) can be generally defined as learning that involves interacting with digital games in a formal or informal setting (Prensky, 2003). Two of the most popular arguments for why digital games may be beneficial for learning are that 1) digital games are motivational, and 2) digital games allow learners to explore complex problems which resemble ill-structured problems in real-life scenarios.

Digital games as motivational tools

Earlier studies of DGBL sought to identify motivational features of digital games that engage learners (e.g., Cordova & Lepper, 1996; Driskell & Dwyer, 1984; Malone & Lepper, 1987). These studies argued that students would engage in active learning if schools could adapt the features that make games motivating to their curriculum. In other words, the goal of these studies is to understand what makes games *fun*, not what makes them educational.

Various motivating features were identified, including challenge, curiosity, control, fantasy (Malone & Lepper, 1987), rules, sensory stimuli (Garris, Ahlers, & Driskell, 2002), and story (Baranowski et al., 2003; Dickey, 2007). Malone and Lepper (1987) argue that challenge is facilitated by undetermined results. Because the players do not know whether they can reach a goal with their existing skill and knowledge level, they are motivated by the challenge. Curiosity is facilitated by an optimal level of complexity. An interesting game is novel and surprising which invites players to explore different aspects of it, but the game cannot be incomprehensible so that the players feel lost and lose interest. Control is motivating because it gives players a sense of empowerment. An empowered player feels motivated because his or her skills and knowledge can influence the environment and outcomes (Malone & Lepper, 1987). Fantasy is motivating because it provides a safe environment for players to apply and play with skills that they have acquired. Rules are motivating because they offer a set of boundaries and restrictions in which the player can explore, challenge, and socialize with other players (Garris, Ahlers, & Driskell, 2002). Some players are also motivated by the sensory stimuli that digital games offer, it maybe a particular art style, or a pleasant music. Baranowski et al. (2003) argues that stories are also motivating as they are narratives about the conflicting interest between the characters and the environment. Stories motivate players to go on because players usually identify with the protagonists and want to find out what happens to them.

These studies explain why games may be fun and motivating, which is important to facilitate self-learning. But they do not focus on the unique media affordances of digital games.

In other words, this line of research does not explain why and how games can be educational, and what kinds of learning are involved when a learner interacts with digital games.

Digital games as complex problem-solving

The other argument for why digital games are educational is that most digital games are inherently complex problems to solve (Gee, 2003). The problem-solving nature of digital games makes them ideal environments for learning and practicing systematic thinking (Gee, 2003, 2007; Squire, 2005).

Instead of communicating the narratives directly to learners, digital games communicate the narrative and educational contents to learners through the interactive experience of problem-solving. Bogost (2007) used the term *procedural rhetoric* to refer to this process of communicating through problem-solving interactivity. Educational digital games rarely reveal the intended messages to the players explicitly. Instead, DGBL exposes players to a complex simulated environment with specific rules and mechanics governed by the code, where players must learn to navigate and interact within the rules. Digital games invite players to learn the mechanics and experiment with different creative solutions in order to reach the games' goals. The narratives of the game are constructed by the player through his or her experience in this problem-solving process. It is believed that this knowledge-construction process can facilitate a systematic understanding of the complex problems.

Digital games are also a type of multimedia which can communicate a combination of video and auditory information. Digital games can simulate environments that allow learners to visualize and interact with factors within their dynamic environment. In order to achieve the games' goals, games often have rules and mechanics that encourage learners to observe the systems' behavior from different perspectives and across time. Many digital games also encourage learners to take on different identities (Garris et al., 2002; Gee, 2007), which facilitates perspective-taking (Peng, Lee, & Heeter, 2010) that generates deeper understanding of an issue and motivates players to take action. Some games allow learners to manipulate variables that are unalterable in real life, pose hypothetical questions and compare the simulated results to their previous understanding of the systems (Squire, 2003). Some games can also support peer-learning among learners through multiplayer designs or discussions outside of the game (Gee, 2007; Steinkuehler & King, 2009).

If we understand digital game based learning as a problem-solving process, we can adopt traditional models of problem solving to examine how working memory is involved in the process of learning through digital games. Newell and Simon (1972) divide the information processing involved in problem-solving into two stages--a *representation stage* and a *solution stage*. The representation stage sets the ground for the solution stage. In the representation stage, learners must first identify the goal of the problem, the important elements related to the problem, the potential actions that can be taken, and the potential constraints of the environment (Wiley & Jarosz, 2012). With the identified information, learners construct a mental representation of the problem in their working memory. Experts who are familiar with the problem domain can often construct the representation faster and to a greater extent than people who are less familiar with the problem domain (Chi, Glaser, & Farr, 1988).

After the problem representation is constructed, the process moves into the solution stage. In the solution stage, learners actively search and activate related information stored in their long-term memory. The information may be a schema, a problem-solving strategy, or a set of algorithms. Following activation, working memory is used to integrate the representation to the activated information in order to construct a potential solution. Once the solution has been applied, learners evaluate whether the solution reached the intended goal. If the solution succeeds, the experience can be integrated into long term memory for future retrieval. If the solution fails, learners might go back to the representation stage or the solution stage to work out an alternative solution. Working memory is involved in both the *representation stage* and the *solution stage* of problem-solving.

Working Memory Capacity in Digital Games

Some of the most comprehensive research about the demands of working memory in digital games is series of studies using the game *Space Fortress* which was created in the 1980s and is still used in research today (Shebilske et al, 2005). *Space Fortress* is computer game developed specifically by cognitive psychologists for studying the acquisition and processing of complex skills and problem-solving (Donchin, 1995). The goal of the game is to navigate a space ship through a number of obstacles and shoot missiles to destroy a space fortress. Unlike traditional studies of working memory which use relatively simple tasks, *Space Fortress* was designed as a regular computer game to study cognitive processing of complex tasks. Studies showed that playing *Space Fortress* involved perceptual motor skills, accurate timing of responses, as well as short and long-term strategic decisions (Logie et al., 1989). Logie et al. (1989) identified eight types of secondary tasks, each with a matching working memory component or function and assigned players to do them while playing, to test what components of working memory were involved in playing *Space Fortress*. Their findings showed that except for articulatory suppression, which suppresses rehearsal, doing all of the secondary tasks while playing resulted in impairment of performance in Space Fortress. In other words, playing a game like Space Fortress involves a large set of demands on working memory, ranging from divided attention, multitasking, visual scanning, dynamic and discrete motor control. Playing a digital game requires players to not only process different cognitive task, but also switch between cognitive tasks. This ability for task-switching requires more working memory in the form of executive control (Gopher, 2006).

More interestingly, in a follow-up study (also reported in Logie et al., 1989) found that visual-spatial processing was only prominent in earlier training phases, and that the effect of visual-spatial processing on working memory load diminished with further training. One possible explanation is that visual-spatial processing became automatic as learners gained gaming expertise. A more recent study showed that expert gamers could monitor a larger number of moving objects than non-gamers (Green & Bavelier, 2006). Boot, Kramer, Simons, Fabiani, and Gratton (2008) found that expert gamers could track objects moving at greater speeds, were more accurate in a visual short-term memory test, performed task-switch more quickly, as well as monitored and evaluated rotating objects faster and more accurately.

The series of study using *Space Fortress* suggests that playing digital games entails complex cognitive tasks which require a series of mental processing and motor skills. Of the cognitive tasks involved in playing digital games, visual-spatial processing such as navigation are prerequisites that are required to advance in a game and are often mastered first. When the players master visual-spatial processing in a game, they can process related visual-spatial tasks automatically, freeing up working memory capacity to process other information within the game.

What is Working Memory?

Working memory is a construct that involves temporarily storing and processing information during cognitive processing (Baddeley, 2007). Working memory has been found to be closely related to a wide range of high-level cognitive abilities such as comprehension, reasoning, and problem-solving (Yuan et al., 2006).

Research about limited working memory capacity can be traced back to Hermann Ebbinghaus's study of learning and forgetting in 1885. Ebbinghaus conducted a series of experiments on himself as he attempted to acquire and forget a series of nonsense syllables. One of his observations was that he often had a fleeting grasp of the nonsensical syllables. However, this temporary memory was insufficient for him to recall the information later (after 31 days). Around the same time, James (1890) proposed that in order for information to be recalled later, the information must be consciously held for a moment in one's *primary memory*. If the information is held in one's primary memory, it can then be stored in one's *secondary memory*, which is an unlimited storage of knowledge that can be accumulated and lasts a lifetime (Cowan, 2008).

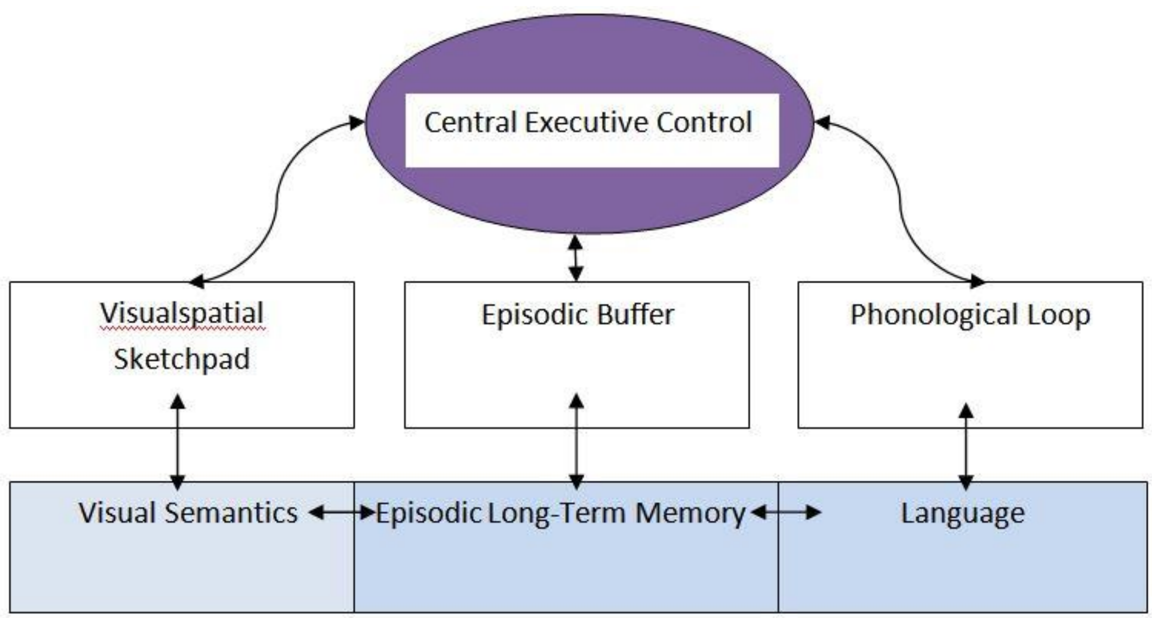
The assumption of a limited working memory capacity was later popularized by Miller's (1956) study of immediate memory span. Miller proposed that people have a limited capacity of immediate memory, in which seven plus or minus two *chunks* of information can be held and processed at any given time. A chunk of information is a group of meaningful elements that a person recognizes. For example the numbers 1800 may be remembered as four independent numbers (1, 8, 0, and 0) to one person, but for another person who is familiar with United States toll-free telephone numbers, the four numbers in 1800 could be stored and processed as one single chunk. In this sense, whether a set of information is considered a chunk depends on one's existing knowledge, his or her ability to recognize the relationships, and ability to make the connection between the information and one's existing knowledge. Miller (Miller, Galanter, & Pribram, 1960) later referred to this temporary cognitive space for storing and processing information chunks as *working memory*.

Following the assumption of limited cognitive capacity, Atkinson and Shriffrin (1968, 1971) proposed a model of short and long-term memory. According to their model, information from external stimuli is acquired through sensory registers (i.e. visual, auditory) into one's short-term memory system. Information in the short-term memory decays fast and if not overtly or covertly rehearsed, the information will be lost. The rehearsed information is then stored into one's long-term memory, which is assumed to have unlimited in capacity and to be relatively permanent. In this model, short-term memory acts as a temporary space in which information is encoded, maintained, and rehearsed to be stored into long-term memory. One of the important contributions of this model is that it highlights the *executive control* function of short-term memory. Atkinson and Shriffrin (1971, p.5) suggested that "because control processes are centered in and act through STS [short-term memory store], this store is considered to be a *working memory*: a store in which decisions are made, problems are solved, and information flow is directed." In other words, working memory is not merely a storage space; it also encompasses attention control functions.

While Atkinson and Shriffrin's model was conceptually sound, empirical tests found it problematic because it failed to explain how long-term memory could be retrieved to influence short-term memory. It also failed to differentiate the storage and control functions of working memory. For example Coltheart (see Baddeley & Hitch, 1974) found that semantically similar words disrupted memory more than acoustically similar words, indicating that long-term memory rather than short-term memory was being disrupted. A series of studies found that patients with impaired short-term memory could perform tasks that used long-term memory just as normal people could. This would not be possible if the executive control was governed by short-term memory (Baddeley & Hitch, 1974).

In order to address the shortcomings of the Atkinson and Shriffrin's model (1971), Baddeley and Hitch (1974) proposed a multi-component model of working memory. Their model consists of an attention control component, the *central executive* which controls two subsidiary slave systems—the *phonological loop* and the *visual-spatial sketchpad*. And two decades later, Baddeley (2000) added another component—the *episodic buffer* to explain how complex information that consists of multi-dimensional message are processed and connected to long-term memory. (See Figure 1).

Figure 1 Baddeley's (2000) structural model of working memory (For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this dissertation)



Baddeley and Hitch's (1974) model became the dominant model of working memory, and two general research directions developed out of this model of working memory (Miyake & Shah, 1999). The first approach focuses on the *structure* of working memory and seeks to understand how information is processed in the working memory by testing this multi-component model (Yuan et al., 2006). The second approach is focused on the *attention control function* of working memory; scholars in this direction seek to understand how individual differences in working memory capacity affect performance in various cognitive tasks (e.g., Cowan, 2008; Unsworth & Engle, 2007). These two approaches to studying working memory complement each other as one focuses on identifying the components and limits of working memory, while the other seeks to understand the cognitive and behavioral influences of limited working memory capacity (Logie, 2011). Because the first goal of this dissertation is to investigate how individual differences in working memory capacity affect attention and comprehension from educational games, this manuscript will only briefly review the structural approach and will primarily focus on discussing the individual difference approach which emphasizes the attention control function.

The Structure of Working Memory

The multi-component model of working memory by Baddeley and his colleagues (see Baddeley, 2007 for review) proposed that working memory consists of a central executive component which controls the flow of information. The central executive determines which information to attend to, and which ones to omit. It is also responsible for determining the associations between information and strategies for processing information. The central executive can be seen as an attention controller with limited capacity which oversees all information processing in working memory. The central executive is purely an attention control system with no storage capacity (Baddeley, 2000)

Since the central executive control has no storage capacity, it controls three subsidiary systems of storage and processing. First, the phonological loop comprises of a phonological store which holds speech-based information and an articulatory rehearsal component which retains information through rehearsal. Phonological information that is not rehearsed through articulatory rehearsal fades in about two seconds. Evidence of the phonological loop includes the phonological similarity effect—words that sound similar are more difficult to recall than words that look similar or have similar meanings (Conrad & Hull, 1964). The word-length effect shows that it is easier to recall short words than long words, possibly because it takes less time to rehearse short words, and thus more rehearsal could be conducted before the word fades (Baddeley, 2000). Further support for the rehearsal process is found in experiments that use articulatory suppression, when rehearsal is prevented by asking experiment subjects to recite an irrelevant sound while trying to remember a list of words. Their performance in word recall drops drastically. Articulatory suppression also removes the word-length effect; if the words are not rehearsed, no matter how long the words are, they are difficult to recall (Baddeley, 2007).

Similar to the phonological loop, the second subsidiary component—the visual-spatial sketchpad holds and process visual-spatial information. It is limited by the visual complexity of the represented information, including the number of stimuli (Luck & Vogel, 1997).

The distinction between phonological and visual-spatial components has been largely supported by various behavioral and developmental psychology studies and also some neuroscience studies (see Baddeley, 2007 for review). However more evidence suggests that the two subsidiary components cannot account for all the information processing that occurs in working memory (Baddeley, 2000). For instance, the earlier model (Baddeley & Hitch, 1974) cannot explain how chunking occurs. Are chunks of information stored in long-term memory? Or are they stored in one's phonological loop? How could a patient with damaged phonological memory limited to one word remember up to five sentences (Baddeley & Hitch, 1974)? More problematic is that children seemed to rehearse information before they learned adult vocal rehearsal strategies (Baddeley, 2000). Where in one's working memory are these information processed if not in the phonological loop or the visual-spatial sketchbook?

In response to the limitations of his original model (Baddeley & Hitch, 1974), Baddeley (2000) incorporated a third subsidiary component—the episodic buffer, to the model. According to Baddeley (2000, p. 421), the episodic buffer is:

> *A limited-capacity temporary storage system that is capable of integrating information from a variety of sources. It is assumed to be controlled by the central executive, which is capable of retrieving information from the store in the form of conscious awareness, of reflecting on that information and, where necessary, manipulating and modifying it. The buffer is episodic in the sense that it holds episodes whereby information is integrated across space and potentially extended across time*.

The episodic buffer is where information retrieved from long-term memory is temporarily stored for processing. While more studies are needed to test this new component, Baddeley (2000) suggests that the episodic buffer is an interface for integrating information from multiple systems and forming new cognitive representations. Therefore it is the component most relevant to processing complex information and problem solving. If this is the case, the episodic buffer maybe the most relevant component to DGBL which comprises of simultaneously processing multi-modal information, active decision-making and problem solving.

It is important to note that while the same words-- *limited capacity* are used to describe the central executive and the three subsidiary components, there are actually two types of capacity involved in the conceptualization of working memory. The first is an *attention capacity*, which is the amount of effort or resource that can be allocated to processing relevant information and blocking out irrelevant information. The second is a *storage capacity*, restricts the amount of information that can be temporarily held and processed in one's working memory.

The Individual Difference Approach

Asides from the structural approach, another approach to studying working memory focuses on the effects of individual differences in working memory capacity. Individual differences in working memory capacity have been shown to be highly correlated with various cognitive tasks such as reading comprehension (Daneman & Merikle, 1996), creative writing (Abu-Rabia, 2003), mathematics (Bull & Scerif, 2001) and general fluid intelligence (Engle, Kane, & Tuholski, 1999). The current study seeks to examine how working memory capacity affects comprehension from an interactive digital game. Therefore I will focus on the individual difference approach of working memory.

While there are strong evidences to suggest that working memory capacity is a strong predictor of ability to accomplish many complex cognitive tasks. The question is why and how does working memory capacity influence these cognitive tasks? Two explanations based on the functional distinction of *attention capacity* and *storage capacity* has been proposed.

Attention Capacity Difference

Some scholars argued that individual working memory capacity differences lie in the ability to control attention and block out interferences (e.g., Cowen, 2005; Kane, Bleckley, Conway, & Engle, 2001). From a structural perspective, the difference is believed to reside in the central executive function of working memory. During information processing, working memory capacity is involved in three main functions of attention control —activation of information, blocking interference, and suppressing unrelated information.

Attention is required during selection of new information, and also during activation of existing information stored in long-term memory. Information selection could be intentional or automatic. Intentional selection occurs when the individual is cognitively aware of what to look for. For example, a person who is looking for a red car will intentionally focus his/her attention on large red moving objects on the road. Information selection can also be an automatic response to novel, unexpected changes in the environment (Lang, 2000; Lang, Potter, & Bolls, 1999). For example, if a person hears a loud noise in the library, it is difficult not to turn his/her head and seek the source of the sound. Both intended and automatic processing requires working memory to process, but intentional processing usually takes more working memory than automatic processing. Furthermore, to determine if the information is related and makes sense, and to further process the information, there is a need to activate information from long term memory (Conway & Engle, 1994). Individuals with higher working memory capacity can retrieve goal-relevant information faster and more accurately than individuals with lower working memory capacity (Barrett, Tugade, & Engle, 2004). Higher working memory capacity also predicts faster generation of category exemplars (Rosen & Engle, 1997).

Because information within working memory is assumed to decay over time, attention is required to maintain information in an active, accessible state for processing and storage. In order to maintain information in an active state, it is also necessary to simultaneously block out interfering information from external and internal sources. For example, when shopping for fruits at a market, one needs to focus on the goal of selecting fruits, while blocking out external interference from other vendors, and also irrelevant internal interference such as thoughts about one's work and family relations.

Individuals with lower working memory capacity are more susceptible to distraction, even if they are instructed to ignore distraction (Kane et al., 2001). For instance, individuals with lower working memory capacity were slower to complete a counting task when distracting information was present (Tuholski, Engle, & Baylis, 2001). Several studies used the antisaccade task to test for the effect of working memory capacity in resisting interference. An antisaccade task requires subjects control their attention and "look away" from an interfering signal in order to see a target message. Findings from these studies showed that individuals with higher working memory are faster and more accurate in recalling the target message (Kane et al., 2001; Unsworth, Schrock, & Engle, 2004), which suggest that they are more capable of controlling their attention and resisting automatic orienting responses to novel stimuli.

Working memory is also involved in the controlled suppression of automatic information-processing that is unrelated to the goal. Individuals with lower working memory capacity are less capable of suppressing automatic or habitual responses. Kane and Engle (2003) used a Stroop test to test the suppression of automatic responses. In Stroop tests, the subjects are instructed to answer the color of the ink that the words are printed in. (The words themselves are names of colors, but the color of the ink and the word sometimes do and sometimes do not match.) Their findings showed that individuals with higher working memory capacity made fewer errors on incongruent trials (e.g., the word RED printed in green ink) than individuals with lower working memory capacity. The finding supports the hypothesis that individuals with higher working memory capacity are more capable of focusing their attention on the goal and inhibiting automatic responses.

Another study by Kane and Engle (2000) used a proactive inference task in which they asked subjects to recall three lists of 10 words. All of the words were drawn from the same categories (e.g., animals, plants, etc.). Between being shown the lists, the subjects were asked to perform an interference task (something unrelated to the word list) for 16 seconds. Recall of the words in a proactive inference task usually drops with each successive list, because words from the previous lists can interfere with later lists. Their findings showed that while all the subjects showed a decrease in words recalled from later lists, subjects with low working memory performed significantly worse, suggesting that they were less competent in blocking out interference coming from previous lists. This evidence indicates that individuals with higher working memory capacity were more capable of focusing their attention on goal-related information and suppressing unrelated external or internal information.

Since working memory capacity mainly reflects ability to control attention and block internal or external distraction, individual differences in working memory capacity will be more significant on tasks that demand active attention control. Such situations includes (a) when there are goals that needs to be actively maintained; (b) when there are competing goals and actions that must be scheduled to prioritize one over the others; (c) when conflicts between actions must be resolved; (d) when controlled, planned search of long-term memory is needed; and (e) when error monitoring and correction are required to reach the goal (Engle, Kane, & Tuholski, 1999).

Kane and Engle (2003) conducted a series of studies to test how task demands for working memory affect the significance of individual differences in working memory capacity. They conducted a series of Stroop tests that required subjects to identify the color of the ink in which words are printed in. They had different ratios of congruent (RED printed in red ink) and incongruent (RED printed in green ink) words. Higher ratios of congruent words required more active attention control because they required subjects to inhibit their habitual response in order to identify the color of incongruent words. The researchers found that when there were no or few congruent words, performance between high and low working memory subjects did not differ. But when there were more congruent than incongruent words (i.e. more habitual interference that demands more attention control), subjects with lower working memory capacity performed significantly worse than subjects with higher working memory capacity. The findings suggest that working memory capacity differences are largely determined by individual ability to control attention, and that the difference is more likely to be significant in tasks that require active attention control in a context with much interference.

A nice analogy for understanding this finding is to think of a staring contest, in which two contestants are competing over who can stare for a longer time without blinking their eyes. Contestant A can stare for 50 seconds without blinking, contestant B can stare for 20 seconds without blinking. If the contest only runs for 20 seconds, there would not be a difference between contestant A and B. However, if the contest runs for 30 seconds (and therefore requires more attention control), the individual differences in attention control between contestant A and B would significantly influence their ability to win the contest.

Digital games are designed to have player goals and designed-goals. Player goals are such as defeating an enemy or collecting objects. Educational games also have learning designed-goals, which the game designers hope players will learn even though the educational goals (such as learning knowledge or skills) are sometimes not what players consciously strive to achieve. Working memory capacity may influence players' ability to focus their attention on player goals, often including cognitive functions such as prioritize certain sub-goal over others, strategically selecting and resolving conflicting actions, actively searching and processing goal-relevant information while restraining themselves from distraction that are unrelated to the goal (e.g., a beautiful soundtrack, cute character design, etc.. And then players use any remaining working memory capacity to absorb and process the knowledge or skill learning content embedded in the game. These two demands on working memory capacity (attention to gameplay and comprehension of learning content) will be considered separately. Similar to Kane and Engle's (2003) arguments, individual difference in working memory capacity is most likely to be a significant predictor of attention in games that require attention control. Some games are designed to reduce working memory demand through scaffolding, which I will discuss later. But often educational digital games are introduced to learners without any scaffolding, which imposes large amount of working memory demand on learners. Therefore the study hypothesize that working memory capacity will positively predict attention to gameplay in the absence of scaffolding design to reduce cognitive load, that is, when the task (e.g., playing the educational game) demands the highest attention control.

H1. Working memory capacity (Ospan score) will positively predict attention to the game (i.e. slower secondary-task reaction time) in the no-scaffolding condition.

Storage Capacity Difference

Another view of individual differences in working memory capacity emphasizes difference in storage capacity. According to this perspective, working memory capacity affects the *amount* of information that an individual can hold and process within a time frame. An individual's working memory capacity is assumed to be fixed, but the amount of information that can be processed is determined by characteristics of the information elements and the domain-expertise of the individual. For example, a large string of words may be more difficult to recall (word-length effect) than a short string of words, but words that are associated with each other in some way (such as conceptually or structurally) are easier to recall than unrelated words for an individual who is able to recognizes and strategically make these kinds of associations because he/she can process multiple related words together as a single chunk of information.

In this sense, having a higher working memory capacity could mean two things—that the individual has a larger storage capacity, or that the individual has a more effective information processing strategy (e.g., chunking). Being able to hold more elements simultaneously allows individuals to rehearse and make connections between more information chunks before they decay (Baddeley, 2000). Storage capacity is especially important when processing information that is highly interrelated and dynamic, thus cannot be broken down into smaller elements and must be processed simultaneously.

One major problem with conceptualizing working memory capacity as storage capacity is that it is highly influenced by individual strategies and individual expertise in the domain. An expert at forming information chunks can store substantially more information; studies have found that experts who can recognize and process information in chunks could expand their digit span recall from a typical amount of seven digits to 80 or more digits, but not on materials that they were not familiar with (Ericsson, Chase, & Faloon, 1980). Since storage capacity is dependent on expertise and strategy, conceptualizing working memory capacity as a storage capacity also cannot explain why the construct is so highly correlated with various cognitive tasks and even correlated general fluid intelligence tests (Abu-Rabia, 2003; Daneman & Merikle, 1996; Engle, Kane, & Tuholski, 1999).

Engle, Tuholski, Laughlin, and Conway (1999) used structural equation modeling to test the relationship between working memory (storage capacity plus attention control) and short-term memory (pure storage capacity) on predicting general fluid intelligence. They found that working memory and short-term memory were correlated but distinct. When variances explained by the common factors were removed, working memory was still correlated with fluid intelligence, but short-tem memory was not. The finding supports the perspective that working memory consists of both storage capacity and attention capacity functions. However, individual differences on complex cognitive tasks may be largely influenced by the attention control capacity of working memory rather than storage capacity.

Domain-Related Expertise and Comprehension

Besides working memory capacity, many studies have also identified domain expertise as a significant predictor of performance on cognitive tasks such as problem-solving. For example, Spillich, Vesonder, Chiesi, and Voss (1979) found that subjects who are knowledgeable about baseball could recall and comprehend a story about a baseball game better than participants who were low in baseball expertise. Fincher-Kiefer, Post, Greene, and Voss (1988) compared memory span of baseball experts on neutral and baseball-related words. They found that baseball expertise facilitated memory span of baseball-related words, but not neutral ones. Ericsson and colleagues showed that the amount of information that could be recalled can improve with extensive training and practice of memory strategies (chunking). However, the improvement was limited to the domain-specific information used in the training (Ericsson & Delaney, 1999; Ericsson & Kintsch, 1995).

Chase and Simon (1973) argued that experts have large numbers of domain-specific information chunks stored in their long-term memory. For example, when chess experts encounter a chess set, instead of encoding each individual piece of information (e.g., chess piece position), they can search their long-term memory and retrieve a similar pattern to facilitate their information processing. Consistent with the researchers' assumption, this expertise advantage disappeared when a board of randomly positioned chess pieces was presented. A possible explanation is that when encountering a random chess set, the experts were unable to retrieve existing patterns to facilitate their memory, therefore like novices, they were forced to process individual chess pieces independently. This finding suggests that experts only have advantages when the information can be connected to their existing information chunks. Having prior knowledge about a content domain allows learners to bring to mind a general model in which they can integrate the new information into. Prior knowledge can also be used to fill in the gaps and make connections between the new information. These findings suggest that individual differences in expertise are most likely to be significant predictors of attention when the task matches the existing schema stored in the experts' long-term memory.

In the context of digital game based learning there are two types of important domain expertise involved—expertise in the content domain (*content knowledge expertise*) and expertise in the media of digital games (*gaming skill expertise*). Most of the studies reviewed in this section have focused on how content knowledge expertise (domain expertise) affects comprehension. However, expertise in the communication media may be equally important in predicting comprehension and learning because different media require different sets of skills and procedural knowledge to navigate and process. For example, when reading a book, one usually begins with the first sentence and ends with the last word, reading in a linear direction. Reading involves a combination of skills ranging from word comprehension, syntactic and semantic knowledge, and higher order inferential skills. In comparison, in multimedia such as digital games, a different set of skills are involved, such as navigation skills, visual-spatial searching, awareness of the game environment, and problem-solving skills.

Previous studies have suggested that familiarity with the game genre is an important user characteristic that may affect message recall (Lee & Faber, 2007). Individuals with higher gaming expertise may be more capable of processing the game mechanics and potential actions in chunks or even automatically, which frees up more working memory capacity to process content information in the game. In comparison, a novice without gaming expertise will need to treat all the information (game mechanics, narratives, educational message) as new information and allocate large amount of working memory to process them together. Several studies on advertisement effects in digital games have support the assumption that gaming expertise facilitates greater memory; experienced gamers showed greater brand recall than non-gamers (e.g., Schneider & Cornwell, 2005; Lee & Faber, 2007).

Working memory capacity and gaming skill expertise are assumed to affect digital game based learning because learning in games is a problem-solving experience. The players first need to be able to navigate the game, then they need to actively search for goal-relevant information while blocking out interference to construct their mental representation of the problem-to-solve. Through deductive thinking and experimenting with potential solutions, players learn how the system works and how to solve the problem. This process requires players to hold large amounts of information in their working memory for navigation, representation-constructing, and solution-testing. Therefore it is likely that learners with more working memory capacity will be more capable of maintaining attention to the learning goal in this process. Players with more gaming skill expertise may be able to reduce the amount of working memory needed because they have existing schema to guide them about what to look for and how things may interact in a game context.

From an attention control perspective, on one hand, gaming skill expertise may facilitate attention control by helping individuals identify which information elements are relevant to the goal, and which information to block out. A learner's gaming skill expertise is also a critical factor in searching for goal-relevant information and sustaining attention on that information (Chi, Glaser, & Rees, 1982; Kalyuga et al., 2003). But on the other hand, since the educational goal of the game is not necessarily the same as the goals of the game, even if they have gaming expertise, learners with lower working memory capacity may not have the ability to inhibit habitual responses. In this case, they may process the game with their habitual responses, focusing too much attention on the game mechanics and missing important educational information.

Some studies have examined the relationship between domain expertise and working memory capacity on comprehension. Hambrick and Engle (2002) examined whether overall working memory capacity attenuated or facilitated expertise on recall and comprehension. Their findings showed no evidence of attenuation. Instead, subjects with higher working memory benefitted more from domain expertise than subjects with lower working memory capacity. One possible explanation is that working memory facilitated better attention control, and expertise helped identify what to focus the attention on. Swanson and O'Connor (2009) also examined the relationship between working memory and reading fluency (skill expertise) on reading comprehension. Their finding showed similar support for working memory capacity as a predictor of comprehension beyond reading fluency (expertise) alone. They suggest that because reading comprehension involves a number of interacting sub-processes such as derivation of word meanings, assignment of importance, pacing, etc. most of which involves processing with working memory. These studies suggest that both domain expertise and working memory capacity affect level of comprehension. The current study seeks to examine how working memory capacity and gaming skill expertise affect attention and comprehension in the context of digital game based learning.

This study hypothesizes that gaming-skill expertise can help learners navigate through the games to identify important information to process and irrelevant information to avoid. Similar to the first hypothesis, individual difference in gaming-skill expertise will be most significant in predicting attention when the gaming task demands more attention control.

H2. Gaming expertise will positively predict attention (i.e. slower secondary-task reaction time) in the no scaffolding condition.

However, based on prior studies on expert performance, individual differences in expertise are most likely to be observed when the experts can identify a task as being within their domain of expertise and therefore can retrieve existing representations and solutions from their schema (e.g., Chase & Simon, 1973; Fincher-Kiefer et al., 1988). Therefore this study hypothesizes that gaming-skill expertise will also be a significant predictor of attention when gaming-skills are scaffolded (scaffolding condition). Gaming-skill scaffolding in the forms of tutorials or levels which increase in difficulty are common digital game level design.

H3. Gaming-skill expertise will positively predict attention (slower secondary-task reaction time) in the gaming-skill scaffolding condition (i.e. a common game design technique).

H4. There will be a significant interaction effect between working memory capacity and gaming skill expertise on attention in the gaming-skill scaffolding condition.

Chapter 3

Game Design and Cognitive Load

Different cognitive tasks vary in the amount of working memory required for accomplishing them. As demonstrated by Kane and Engle (2003), individual difference in working memory were more significant on cognitive tasks that required more active maintenance of attention with more distractions. This chapter will begin by reviewing a capacity theory of comprehension from educational media (Fisch, 2000) to explain how educational medium design affects working memory demands and the conditions in which processing of narratives takes priority before understanding of educational content occurs. The next section will discuss the expertise-reversal effect and the reverse-cohesion effects, two seemingly competing explanations of how scaffolding design efforts to reduce working memory demands may unintentionally cause skill experts to perform worse in comprehension than they would without the scaffolding designs.

Fisch's Capacity Model of Comprehension from Educational Media

Fisch developed a model of comprehension based on his extensive experience producing and studying educational television programs for children. His model is based on the assumption of limited working memory capacity and incorporates three major constructs: Narrative, Educational Content, and Distance.

Narrative refers to the surface information such as story, characters, goals, and environment. In comparison, *educational content* refers to the underlying concepts and messages that the media designer intends to communicate. Educational content could include both declarative knowledge (e.g., facts) and procedural knowledge (e.g., problem-solving strategies). *Distance* is the degree to which the educational content is integral to the narrative. The model posits that narrative and educational content compete for working memory capacity, and the distance between narrative and educational content determines how much they compete with one another.

For example, in a *Sesame Street* television program designed to teach about water conservation, understanding the narrative would involve knowing characters such as Big Bird and Elmo, what they were doing in the skit, and the relationship between them and their actions; It would also include understanding their spoken language and their non-verbal cues such as a smiles or tears. The educational content would be the knowledge regarding water conservation such as what actions to take, the underlying reasons for taking action, and potential consequences. If the educational content is tightly woven into the narrative, the distance between narrative and educational content is considered small. If the educational content is not part of the narrative, but requires additional efforts to comprehend, then the distance is large.

One of the key points in this model is the concept of *narrative dominance* (Fisch, 2000). The model posits that comprehension of narrative will take priority when competing with educational contents for working memory, especially when the distance between narrative and educational content is large. This is because most educational media designs embed the educational content within the narrative. Using the example given in the previous paragraph, it is almost impossible for a learner to understand the concepts of water conservation if he/she does not understand the English language that Big Bird and Elmo use to speak, if he/she does not understand what their interaction is about, or if he/she cannot tell if the characters are happy or upset. Only when the learner has some understanding of the narrative can the learner comprehend the underlying message behind the narrative—the educational content. But when the narrative demands too much working memory from learners, there will be insufficient working memory capacity for comprehension of educational content.

Fisch (2000) also points out that learner characteristics such as prior knowledge, familiarity with medium, working memory capacity, and motivations can also influence how much working memory is allocated to processing the narrative and educational content. Learners with more prior knowledge about the narrative, and those who are familiar with the way educational content is structured in the medium will be able to process the narratives in chunks and be able to allocate more of their unused working memory capacity to processing the educational content, which leads to more comprehension. Learners with higher working memory capacity are also more capable of processing educational content above the working memory capacity required to process the narrative. And it is possible that if learners are motivated to learn the educational content, they may intentionally seek out educational content and allocate more working memory to processing it.

Digital game based learning, like educational television programs, often embeds educational content within narratives. On top of that, instead of having the narrative unfold to the learners, interactive digital games require players' active engagement (e.g., decision-making, inputs, etc.) in order to develop the narrative (Klimmt & Hartmann, 2006). Therefore the primary goal of learners in DGBL is learning how to engage the game by learning the controls and game mechanics. Their second goal is to understand the narratives developing from their interaction with the game design (Grigorovici & Constantin, 2004; Lee & Faber, 2007). Only after the game controls are mastered and the game narratives are understood will learners be able to allocate their working memory capacity to processing the educational content.

Scaffolding, Expertise-Reversal Effect, and Reverse-Cohesion Effect

If mastering controls and understanding narratives are prerequisites to understanding the educational content in games, what can educators and game designers do to increase learner's available working memory and thus improve learner comprehension? One potential solution is through scaffolding designs. Scaffolding is an instructional strategy that supports novice learners by limiting the complexities of the educational context and gradually removing these supportive limits as learners gain the knowledge, skills, and confidence to cope with the full complexity of the context (Young, 1993). Complexity here refers to the number of interacting information elements in the problem-solving task (van Merriënboer & Sweller, 2005). By initially exposing learners to a less complex version of the educational media, learners will have less information that needs attending to and less distraction; therefore they can focus on building up knowledge about the content or skills regarding the media. With the knowledge and skills, they can allocate less working memory to processing the controls and narrative and have more available working memory for processing the educational content. Azevedo and Hadwin (2005) argue that scaffolding can aide learners in: (a) acquiring domain knowledge, (b) acquiring procedural knowledge, (c) learning how to use the instructional tools, and (d) learning how to engage instructional features or contexts.

In the context of digital game based learning, there are two common scaffolding strategies for reducing cognitive load. First, cognitive load demands can be reduced by providing explicit instructions, so that the learner does not need to work to figure out what information are relevant, and how does the relevant information interact with one another (content-knowledge scaffolding). This design can mitigate the amount of cognitive efforts that learners need in order to understand the narrative and constructing a mental representation. Second, levels can be designed with increasing difficulty that allows learners to gradually learn the controls and narratives in early levels (gaming-skill scaffolding). After the learners master one section, they are introduced to the next section until the complete complex problem is revealed. On the first level, players are given limited actions and relatively simple goals (e.g., move from point A to point B). This approach allows players to familiarize themselves with the basic controls and game mechanics. As the players progress through levels, they are given more available actions and more goals and obstacles, until the player builds up a repertoire of skills to engage the complex problem. Skill scaffolding can also help learners identify what belongs to the controls and narratives, and what new information is included later. In other words, game scaffolding designs such as explicit instructions and levels seeks to reduce cognitive load and improve comprehension of educational content by helping learners gain narrative or gaming controls expertise. While scaffolding has shown to help learners with lower expertise, several studies have observed that learners with higher expertise do not benefit and sometimes even suffer from scaffolding designs. For example, Yeung, Jin, and Sweller (1998) found that the addition of explanatory text (knowledge scaffolding) made learners with high reading competence (skill expertise) perform worse in comprehension of the text. High-reading competent learners also reported more cognitive efforts in processing the explanatory text condition. Kalyuga et al. (2001) found that inexperienced mechanic trainees benefitted most from studying case examples of worked models, whereas experienced mechanics benefitted most from having problems presented for them to solve. Kalyuga and colleagues (Kalyuga et al., 2003; Kalyuga, Chandler, & Sweller, 2000) refer to this phenomenon as the *expertise-reversal effect*.

One potential explanation for the expertise-reversal effect is that, unlike novices who do not have existing schema and skills to aide them in processing the problem, experts are capable of processing the problem using their existing mental representations. The addition of scaffolding information may provide a model for the novice learners and thus free up working memory capacity for comprehension. But for experts, the scaffolding models may conflict with their existing mental representation or familiar approach. Therefore, instead of reducing cognitive efforts, the experts need to allocate more working memory in order to cross-reference and integrate the explicit information with their existing mental representations. Even if the expert learners recognize the explicit information to be redundant and decide to avoid it, they still need to allocate additional working memory in order to block out the explicit information as distraction. Therefore according to this explanation, experts would have less available working memory when scaffolding is provided than when no scaffolding is given.

H5a. Players with higher gaming skill expertise will have more attention to the game (i.e. slower secondary-task reaction time) in the gaming-skill scaffolding condition than the no scaffolding condition.

H5b. Players with higher gaming skill expertise will have more attention to the game (slower secondary-task reaction time) in the content-knowledge scaffolding condition than the no scaffolding condition.

Similar results were observed in a series of studies conducted by McNamara et al. (1996) in their study to investigate the relationship between expertise, text coherence and comprehension. The purpose of these studies was to investigate whether accommodating learners and making the learning experience “trouble-free” was an optimal approach for learning. McNamara et al. (1996) compared content experts and novices in their comprehension of a coherent or incoherent text about biology. The coherent text included background information and identified relationships between information. In contrast, the incoherent text required learners to actively fill in the information gaps and make relational inferences with their existing knowledge. In other words, the coherent text can be seen as a type of scaffolding that requires less working memory on the part of novices to process than the incoherent text (Ozuru, Dempsey, & McNamara, 2007). They found that novices (those who had with lower content expertise) benefitted from the coherent text, but experts with higher expertise learned less with the coherent text than when the text was incoherent. McNamara referred to this as the *reverse-cohesion effect*.

McNamara et al. (1996) argued that scaffolding through text cohesion helps novices because they do not have preexisting schema to fill in the information gaps and make inferential connections between information elements. However, by reducing complexity and working memory demand, coherent text gives expert learners a “false sense of understanding” and the experts tend to process the information only superficially and may miss important information. On the other hand, incoherent text with the information gaps required learners to actively use their existing schema and knowledge to fill in the gaps and comprehend. Consequently, learners with more content expertise exerted more working memory to process the incoherent text (i.e. they pay more attention), and also comprehended more of the information. Due to the reverse-cohesion effect, McNamara et al. (1996) proposed that reducing working memory demands may not be the optimal strategy for engaging learners who have content expertise. Instead, it may be beneficial to provide learners who have content expertise with educational media that is less cohesive and require their active attention.

The expertise reversal effect and the reverse-cohesion effect may seem to predict similar results, that novice would benefit from scaffolding, but not experts. However the two models differ in their definition of “expertise,” and the underlying mechanism. Kalyuga et al.’s (2000,

2003) expertise-reversal effect does not differentiate between content knowledge expertise and skill expertise; they perceive expertise as a whole set of content knowledge, mental models, and skills that is acquired through more experience with a task. Therefore they often use the terms *experienced* and *inexperienced* to differentiate experts and novices (Kalyuga et al., 2003). On the other hand, the expertise in McNamara et al.'s (1996) original study was specifically about content-knowledge expertise. In other words, the predictions derived from McNamara's earlier reverse-cohesion effect were about how prior knowledge of the contents may affect how learners engage the text. Their earlier study did not examine how skill expertise such as reading proficiency, familiarity with text structure, experience with learning through text, and learning strategies affect learner response to scaffolding.

The underlying mechanism for why experts do not benefit from scaffolding was also different. The expertise-reversal effect posits that scaffolding introduces redundant information for experts, which uses up more working memory. In contrast, the reverse-cohesion effect posits that scaffolding makes the tasks easier for content experts, and therefore induces superficial processing. In other words, the expertise-reversal effect argues that scaffolding increases working memory demand, whereas the reverse-cohesion effect argues that scaffolding reduces the likelihood that content experts will choose to allocate as much working memory to the task.

Several recent studies have compared how content expertise and reading skill expertise predict text comprehension (Best, Rowe, Ozuru, & McNamara, 2005; O'Reilly & McNamara, 2007). These studies found that the reverse-cohesion effect occurred only among learners with high content expertise and low reading skill expertise, not among learners with both high content expertise and high reading skill expertise. The author argued that learners with higher reading skill expertise will not be affected by the addition of explicit information because they are capable of handling the increased amount of information.

Unlike the linear text which McNamara and her colleagues examined, digital games are more similar to multimedia hypertext which requires large amounts of cognitive effort to integrate and comprehend. Multimedia hypertexts also impose higher demands on the attention control from learners (Shapiro & Niederhauser, 2004). Because games' information and narrative are often non-linear, skills in navigating and searching may be particularly important (Azevedo, Guthrie, & Seibert, 2004). Prior studies have found that learners with lower content knowledge struggle with comparing and integrating multiple representations presented in a non-linear way (Ainsworth, 1999; Yersuhalmy, 1991). In comparison to content knowledge expertise, much less is known about how media skill expertise affects available working memory and comprehension. Several studies on hypertext comprehension have shown that media skill expertise is one of the strongest predictors of comprehension when reading hypertext (e.g., Ford & Chen, 2000; Reed & Oughton, 1997). Since learners need to actively navigate between information elements in a hypertext environment, gaming-skill expertise may help learners navigate through the information and construct mental representations based on gaming schema.

Both the expertise-reversal effect and reverse-cohesion effect predict that experts will comprehend more of the educational content in the no-scaffolding condition than in the scaffolding conditions.

H6. Players with higher content expertise will have highest comprehension in the no-scaffolding condition in comparison to the scaffolding conditions.

However, the expertise-reversal effect is based on the assumption that less cognitive load improves comprehension; whereas the reverse-cohesion effect argues that if the learner has sufficient expertise, more cognitive load improves comprehension. Therefore the study poses a research question:

RQ1. Will available working memory positively or negatively predict comprehension?

Finally, scaffolding designs are intended to support learners with lower expertise and improve their comprehension. The last two research questions in this study examine 1.) Whether gaming-skill scaffolding design supports learners with low gaming skills and improves their comprehension and 2.) Whether the content-knowledge scaffolding design support learners with low content knowledge and improves their comprehension.

RQ2. Does gaming-skill scaffolding improve comprehension for low gaming-skill learners?

RQ3. Does content-knowledge scaffolding improve comprehension for low content-knowledge learner?

Chapter 4

Experiment Design and Measurements

The goal of this study is to examine the effect of individual working memory capacity and gaming skill expertise on attention and comprehension of educational content under three common game designs (no scaffolding, gaming skill scaffolding, and content knowledge scaffolding). The study also seeks to tease apart competing explanations about why experts may not benefit and may sometimes perform worse when provided with scaffolding. An experiment was designed to test the hypotheses.

Participants

Participants in this study were recruited from five undergraduate-level courses in the College of Communication Arts and Science at Michigan State University. Extra credit was offered by the course instructors as incentives for participating in the experiment. A college-student sample is appropriate for this study because the current generation of college students is familiar with digital games. According to a national survey by the PEW Research Center's Internet and American Life Project, 81% of people aged between 18 to 29 years old play digital games, and 76% of people in this age group play games on their computers (Lenhart, Jones, & Macgill, 2008). Furthermore, a relatively homogeneous sample is preferred in a lab experiment for theory-testing. This is because a homogeneous sample reduces the chance of making a false conclusion about whether there is covariance between variables. In other words, using a homogeneous sample reduces the chance of committing a Type II error in which the theory is disconfirmed when in fact there is variance that is obscured by third variables when using a heterogeneous sample (Calder, Phillips, & Tybout, 1981).

A total of 182 participants were recruited for this experiment. The mean age was 21.05 years-old (*SD*=2.40) and ranged from 19 to 38 years old. There were slightly more males (54.8%, *N*=100) than females (45.2%, *N*=82) in the study.

Stimuli and Learning Goals

The educational game used in this study is *The ReDistricting game*. *The ReDistricting game* is a game designed to educate players about the issue of political redistricting. Specifically, the game is intended to help students understand the problem of gerrymandering. Gerrymandering is the act of manipulating inclusion or exclusion of residential blocks or other geographic parameters used to define voting districts to gain advantage for certain political parties or interest groups. The ReDistricting game was created at the USC Game Innovation Lab of the USC School of Cinematic Arts' Interactive Media Division. It was developed for the USC Annenberg Center for Communications by a team led by game designer and faculty member Chris Swain.

In *the ReDistricting game*, players take the role of a map maker who draws voting districts. The game consists of five missions. Each mission is divided into *basic* and *advanced* difficulty; the difference between basic and advanced difficulty is the number of elements and constraints. The first mission is a basic tutorial about the controls. The second mission is about partisan gerrymandering, which requires players to draw voting districts to favor a political party they choose. The third mission is about bi-partisan gerrymandering; it requires players to draw voting districts to keep the status quo so both parties' seats are protected. The fourth and fifth mission demonstrate how changes in voting laws can make gerrymandering more difficult and protect a fair election. Through the five missions, players are expected to experience and understand how redistricting (i.e. map-drawing) plays such a large role in directing election results, and could easily be manipulated to undermine fair competition between candidates—a foundation of democratic society. The game website also includes additional information about gerrymandering and links to take action by sending a letter to state senators.

The ReDistricting game has two educational goals: to facilitate comprehension about the problem of gerrymandering, and stimulate discussion and action about the problem. According to the game description on the website, *the ReDistricting game* provides "a basic introduction to the redistricting system, allows players to explore the ways in which abuses can undermine the system, and provides info about reform initiatives." Therefore, the first learning goal is comprehension about the potential problems of redistricting, particularly. According to the lead designer Chris Swain (Swain, 2007), the second learning goal is for players to come up with solutions and take action.

Like many educational games that deal with political problems, *the ReDistricting game* takes a reversed role-playing perspective. In reversed role-playing narratives, the learner takes the role of the problem-maker. The explicit instruction of the game is to reach a certain goal (e.g. in *the ReDistricting game*, the goal is to manipulate election results through gerrymandering), but the underlying educational message is the opposite of that goal (i.e. gerrymandering is bad and undermines democracy). In this type of reverse role-playing design, understanding the game mechanics and narrative does not equal comprehension of the educational message. Players need to have some existing knowledge about the democratic election assumptions and actively reflect on their experience to understand that the game's intended message is the opposite of what they just experienced. Therefore I argue that the distance between narrative and educational content is large in *the ReDistricting game*. According to Fisch's (2000) capacity model, when the distance between narrative and educational content is large, the narrative takes priority and competes with the educational content for working memory.

The ReDistricting game is a suitable game for this study because the game is specifically designed for undergraduate-level students. Most undergraduate students are not familiar with the process and mechanics of gerrymandering, thus they not likely to have extensive content knowledge expertise in the topic of redistricting. If, as expected, there is generally low content expertise across study participants, this sample allows the study to focus on examining how working memory capacity and gaming skill expertise contribute to attention (i.e. the amount of working memory allocated to the task) and comprehension of a little-known topic.

Operational Measures

Independent variables

Scaffolding Conditions. Scaffolding techniques were induced in this study by randomly assigning participants into one of the three conditions (*No scaffolding, Content-knowledge scaffolding* and *Gaming-skill scaffolding*).

Since the main problems of gerrymandering are communicated in Mission 2 of *the ReDistricting game*. The participants in this study were expected to learn the problems of redistricting after playing Mission 2 under the advanced difficulty which contains the complete narrative and educational message with all the interacting elements and legal constraints. The difference between the three conditions was in how the Mission 2 (advanced) was introduced to the participants. The no-scaffolding condition introduced participants to Mission 2 without any skill or content scaffolding. The gaming-skill scaffolding introduced participants to the controls and basic game mechanics before they played Mission 2. The content-knowledge scaffolding provided participants with an explicit message framework about the redistricting process and the game's goal before they played Mission 2.

The no-scaffolding condition has the highest complexity because it includes all the interacting information elements but without any scaffolding. This study posits that the participants will find the no-scaffolding condition most difficult because it imposes the highest working memory demand. Participants in the no-scaffolding condition played Mission 2 of *the ReDistricting game* under the advanced difficulty twice. In the first playthrough participants were instructed to stop playing Mission 2 after five minutes, this allowed participants to explore the game a little without increasing their exposure to the educational message in comparison to educational message exposure experience in the game by the other two conditions. The second playthrough of Mission 2 in the no-scaffolding condition required participants to either complete Mission 2 or play for 30 minutes.

Participants in the Content-Knowledge-scaffolding condition were first instructed to read an article (available on the experiment web site) about the general issue of redistricting and the purpose of the game (see Appendix 2). After confirming that they had read the article, the participants were then instructed to play Mission 2 of *the ReDistricting game* under the advanced difficulty for five minutes, and then a second time until completion or for 30 minutes. Reading the article was expected to reduce working memory demand by providing participants with a general knowledge framework about redistricting and about the game.

Participants in the Gaming-skill scaffolding condition played Mission 1 under the advanced difficulty and then Mission 2 under the advanced difficulty. Mission 1 teaches the players about the basic controls of the game and the basic goal of population equality. It does not include the problem of gerrymandering or the legal constraints on map redistricting.

A comparison of the three conditions is shown in Table 1.

Table 1 Comparison of induced scaffolding conditions

	No scaffolding	**Gaming-skill scaffolding**	**Content-knowledge scaffolding**
Step1	Mission 2 Advanced (5 minutes)	Mission 1 Advanced	Article + Mission 2 Advanced (5 minutes)
Step2	Mission 2 Advanced	Mission 2 Advanced	Mission 2 Advanced

Gaming Skill Expertise. Gaming expertise was measured by a series of 7-point questions in the pre-test survey. Participants' were asked about self reported *familiarity* and *expertise* with a list of different genres including strategy, puzzle, action, sports, role-playing, adventure, etc. The list was randomized to eliminate order effect. Since *The ReDistricting game* is a strategy simulation game, the mean score of familiarity and expertise on strategy and simulation games was used as self-reported gaming expertise. The mean score for gaming skill expertise was 3.48 (SD=1.61). Reliability test using Cronbach's α indicates that the items are acceptable at .68.

Working Memory Capacity. Working memory capacity was measured using the automatic operation span (AOSPAN) test developed by Unsworth, Heitz, Schrock, and Engle (2005). AOSPAN is a self-administered version of the popular operation span (OSPAN) measure of working memory capacity developed by Turner and Engle (1989). In OSPAN participants are asked to solve a series of math operations while trying to remember a set of unrelated words. For example, a set of three questions looks like:

Is 1+ (2*8) =15? [Yes/No] Truck

Is (2/8)-3=1? [Yes/No] Eagle

Is (10-4)/2=3? [Yes/No] Job

The string of math operation and words appear one at a time. After each set of questions, participants are asked to mark a check on the words from a list of words in the correct order. The task requires participants to hold the words in their working memory while processing the math calculations. Working memory capacity score is calculated by the number of correct answers ranging from 0 to 12.

A practice set of three questions was given to participants so that they understand the task. After the practice, three sets of four questions each (total of 12 questions) were used to measure working memory capacity. Based on previous studies (Unsworth et al., 2005), participants were given seven seconds to solve each question before the page moves on, this procedure prevents participants from intentionally rehearsing the words. An 80% accuracy criterion on the math test is used to ensure that participants are processing the math question while holding the words in their working memory instead of just focusing on the words. Twelve participants were removed from the dataset because they did not meet the 80% accuracy criterion. The mean score of the AOSPAN test is 5.98 (out of 12, *SD*=3.66).

Dependent Variables

Attention. Attention is measured through secondary-task reaction time (STRT). Secondary-task reaction time is a measurement commonly used by cognitive psychology studies to measure attention through measuring available working memory capacity (Lang, Bradley, Park, Shin, &

Chung, 2006). It is conceptualized that when the primary task takes more working memory to process, there will be less available working memory to process secondary tasks, which leads to slower reaction time to the secondary tasks.

Secondary-task reaction time is measured by instructing participants to focus on a primary task, which is playing the game in this study. In addition to the primary task, the participants are given a secondary task of pressing a specific button “as fast as you can” when they see a signal. The signal is called the secondary task probe. The latency (time difference) between the probe and the button-pressing action is called secondary-task reaction time (STRT). Theoretically, as more working memory is allocated to the primary task for storage and attention control, the participant will have less available capacity to process the secondary task, resulting in slower reaction time. Available working memory capacity refers to the amount of working memory required by the task minus the amount allocated to the task (Lang et al., 2006). Longer STRT indicates more attention on the primary task, and shorter STRT indicates less attention on the primary task.

In order for the secondary-task reaction time to be an accurate reflection of attention, it is important that the secondary task probe to be in the same message mode as the primary task so that it draws upon the same pool of working memory. The secondary task must also be very simple so that is does not interfere with performance on the primary task (Bru¨nken, Plass, & Leutner, 2003; Marcus, Cooper, & Sweller, 1996).

Since *the ReDistricting game* does not have auditory stimuli, the secondary task is designed in visual mode. In this study, the secondary task probe was a yellow box next to the game screen that appears at random times and in random places, participants were instructed to press the “spacebar” key *as fast as you can* when they see the yellow box appear. STRT is measured by the experiment website by subtracting the time that the participants pressed the spacebar to the time that the yellow box lights up. STRT was record in milliseconds from the onset of the secondary task probe to the time that participant pressed the spacebar key on the computer keyboard.

A total of 16 secondary task probes appeared on random time throughout the stimuli (eight in each mission). The decision of having eight secondary task probes in each playthrough is twofold. One the one hand, *the ReDistricting game* is not a fast-paced game that requires frequent reaction, thus it does not require a large number of secondary task probes. But on the other hand, since the participants in this study are younger, previous studies have suggested that more probes are needed to capture variance among younger populations because of their faster reaction time (Basil, 1994). The number of probes is decided because in my pilot test, the average time for completing mission one is seven minutes, and for mission two is 15 minutes.

Since not all the participants in the study received all eight secondary probes in each mission, if they completed the missions earlier, they were only exposed to the first few probes. In order to allow comparison between participants, only the first five STRT of the second playthrough (in which all three groups played Mission 2 advanced) were included for the analyses. Furthermore, because the first secondary-probe is often missed, attention score in this study was calculated by averaging the second to fifth STRT (four STRT for each participant) in the second play-through in which all the participants played Mission 2 on the advanced difficulty of *the ReDistricting game*. Missed responses (i.e. no response or response after 5000ms from the onset of the secondary probe) were coded as missing data. The mean score for STRT was

1090.45 milliseconds (i.e. 1.09 seconds, SD=489.65), ranging between 461 milliseconds to 3672 milliseconds.

Comprehension. The first goal of *the ReDistricting game* is for learners to understand the potential problems of the redistricting process. Comprehension was measured in two ways. The main measurement used in the hypotheses-testing was a set of 11 multiple-choice questions that test the participants' comprehension of the redistricting process (see Appendix 4 for the questions). Each correct answer was given one point, thus the comprehension score ranges from 0 to 11. The mean comprehension score was 4.84 (out of 11, *SD*=2.31) ranging from 0 to 11. The reliability of the comprehension items were acceptable with α=.67.

The secondary comprehension measurement was a free-recall test that asked participants to "*Explain the potential problems with redistricting process? (Describe as much detail as you can).*" This set of measurements was not used in the statistical analyses, but they provided some insight to the participants' comprehension of the game and unintended effects.

Control Variables

Since *the ReDistricting game* is a political game, prior attitudes about political issue may also influence the results. Therefore political involvement was controlled as a covariate. Political involvement was measured by nine 7-point questions adapted from Kahne, Chi, and Middaugh, (2002). The questions ask participants how much do they agree or disagree with nine statements that describe them. For example, "I often talk about politics and political issues," "I often wear badges in support of certain political issues," and "I vote regularly." The items are reliable with α=.84.and a mean of 2.37 (*SD*=.98).

Existing content knowledge about the redistricting process and gerrymandering may also affect learning outcomes. Two7-point question were used to measure the participants' self assessment of content knowledge: "I am very familiar with the redistricting process" "I consider myself an expert in how gerrymandering works." the questions were designed to be vague so that they do not prime the participants to pay attention to specific parts of *the ReDistricting game*. The two items were reliable at α=.74, the mean for content knowledge was 2.86 (*SD*=1.65).

The scores on political involvement and content knowledge were skewed towards the lower end of the 7-point scale, which suggest that participants in this study generally had low political involvement experience and content knowledge expertise about the topic of redistricting.

Research Procedures

After the participants volunteered for the experiment they were invited by email with a hyperlink to an online scheduler to sign up for a time slot. Before the scheduled date, the participants received an email reminding them to come to the computer lab to participate in the experiment.

On their selected time, upon arriving at the computer lab and receiving the informed consent form, the participants were given a URL that directed them to the experiment website in which all the experiment questionnaires, stimuli, and tests were embedded.

On the experiment website, the participant first answered a short questionnaire measuring their political involvement, their political efficacy, and the two content knowledge questions. After responding to the pre-test questionnaires participants read a detailed instruction about the AOSPAN test. They were given three practice questions to familiarize themselves with the

AOSPAN test. After the practice questions, they took the actual AOSPAN test consisting of 12 math and word retention questions.

After the participants completed the AOSPAN task, they were randomly assigned by the experiment website to one of the three scaffolding conditions. All the groups read an instruction reminding them to pay attention to the game because they would later be tested about the content (see Appendix 2). The instruction serves two purposes. The first purpose was to increase involvement. Previous studies have shown that individual differences in working memory capacity are more significant when the task requires intentional attention control to goal-related information as opposed to incidental learning (Unsworth & Engle, 2005). The second purpose was to frame the game-playing experience as a learning experience, to try to introduce learning as a motivation in approaching the game. A player who is playing a game to learn may have very different behaviors than a player who is playing a game for entertainment or relaxation.

After reading the instruction about the game, the participants were then shown an instruction about the secondary task probe and were instructed to respond "as fast as possible." In order to prevent participants from intentionally neglecting the secondary task instructions, they were told that if they perform poorly in the task, they need to redo the task. Participants who missed all the secondary task probes were removed from the study because they may represent players who are extremely involved in the game that they did not have any available working memory for the secondary probe, or extremely uninvolved participants who paid no attention and were not following the experiment instructions.

In the No-scaffolding condition, participants played Mission 2 (advanced) of *the ReDistricting game* for five minutes first, and then played Mission 2 (advanced) again until they complete the mission or for 30 minutes, whichever happens first. The gaming skill scaffolding group played Mission 1 (advanced) followed by Mission 2 (advanced). The content-knowledge scaffolding group is similar to the no-scaffolding condition, but before playing the game, the participants read a short article describing redistricting and the purpose of the game. Then they played Mission 2 (advanced) for five minutes; and then play Mission 2 again until completion or for 30 minutes, whichever happens first. The behavioral data of participants and their STRT have been programmed to be recorded on the server that is running the game. Access to the source code of *the Redistrincting Game* was granted by the game creator, Chris Swain.

The first two missions of *the ReDistricting game* were used in this study for content and time reasons. It was important for participants to be able to complete participation in less than one hour. And, more importantly, the main problems of the redistricting process (gerrymandering) were communicated in Mission 2. (Mission 3 and Mission 4 reiterate the problem again; Mission 5 discusses one of the many potential solutions to the problem). Thus, Mission 1consisted of built in gaming-skill scaffolding and Mission Two introduced the core learning contents. Missions One and Two optimally suited the study goals of examining the impact of scaffolding on attention and comprehension.

After playing the game, participants filled out a post-test questionnaire measuring their enjoyment of the game/video, their perceived challenge level, and their self-reported effort. These questions acted as distracters before the comprehension test. This is to help ensure that the comprehension test measured information that was stored within the participants' long-term memory. The participants' comprehension was measured with a free recall question first, followed by multiple-choice questions about the educational content in *the ReDistricting game*. The free-recall question was asked first to prevent participants from being primed by the multiple choice questions. Finally, participants answered demographic questions including age, sex, and race. The complete experiment procedures took most people approximately 40 minutes. Seven participants were excluded from the study because they could not complete the procedures within 60 minutes.

Manipulation Checks

The scaffolding conditions were induced in this study by altering how the participants approached Mission 2 (advanced) of *the ReDistricting game*. After completing the first game playthrough, before playing Mission 2 (advanced), participants in all three conditions were asked to rate how difficult did they perceive the first game play-through on a 7-point scale. An analysis of covariance (ANCOVA) was used to analyze the manipulation check with the three scaffolding conditions as independent variables (IVs) and the perceived difficulty as dependent variable (DV). The participants' gaming expertise was controlled as a covariate.

The analysis showed that there was significant difference in perceived difficulty between the scaffolding conditions. F (2, 141) =3.79, P<.05, partial eta squared=.05. As expected, participants in the no-scaffolding condition reported the highest perceived difficulty (M=4.94, SD=1.49, N=49), followed by the content-knowledge scaffolding condition (M=4.64, SD=1.97, N=45), followed by the gaming-skill scaffolding condition (M=4.04, SD=1.8, N=51). Post-Hoc analysis using Bonferroni pair-wise comparisons was conducted. The analysis result showed that there was significant difference in perceived difficulty between the no-scaffolding condition and the gaming-skill scaffolding condition (p<.05). However, there was no significant difference in perceived difficulty between the no-scaffolding condition and the content-knowledge scaffolding condition (*n. s.*). Note that the gaming-skill scaffolding condition, which was perceived by the participants to have the lowest difficulty among the three conditions, still has a mean score of 4.04 out of 7. This indicates that overall, *the ReDistricting game* was considered slightly difficult for the participants in this study even with scaffolding.

Chapter 5

Results

Sample

Seven participants were removed because they could not complete the experiment procedures within 60 minutes. Twelve participants were removed because they did not meet the 80% math accuracy criterion on the AOSPAN test.

Seventeen more participants were removed because they did not respond to any of the secondary task probes while playing the game.

Researchers that measure reaction time almost always face the problem of how to deal with extreme outliers. Outliers in reaction time can be extremely short or extremely long reaction time. Unusual short reaction time can be the result of fast guesses, random tapping, or guesses based on the subjects' estimate of probe timing. Unusual long reaction time on the other hand, can be caused by the uncooperative subjects, inattentive subjects, or conversely, full attention to the primary task (Baayen & Milin, 2010).

Most experimental psychology studies using reaction time follow Roger Ratcliff's (1993) suggestions of removing outliers that are two to three standard deviations from the mean. Ratcliff suggest that on only 85%~95% of the total sample is included in the analysis after removing outliers. Using this criterion, I should remove participants whose response time smaller than 111.15ms (none), and larger than 2065.75 (n=5), and missing (n=17). A visual check on the five participants with longer reaction time was performed, and they were slower in all four STRT included in this study, therefore I concluded that the responses are genuine, reflecting the participants' slower reaction and unlikely a product of non-cooperation or inattention to instructions.

The 17 participants who did not respond to any secondary probe were removed from this study. This is because when the focusing of the measurement if on attention, missed response to secondary probes can indicate two extreme situations: extreme inattention, and extreme attention to primary task. A missed response can be because the participant is fully attentive on the primary task, leaving no available working memory for processing the secondary task. Or it can be because the participant is inattentive to the instructions and the secondary task, or that they are bored about the experiment and are being uncooperative by not doing anything. Unfortunately there is no way of distinguishing the two situations.

Since there is no way of distinguishing inattention from full attention, removing the non-response participants removes uncooperative participants along with participants who are fully focused on the game and have no available working memory for the secondary task. This procedure benefits the study because it removes noise from uncooperative participants which improves the accuracy of the STRT as a measurement of attention. However, this procedure also removed the participants who are so attentive to the game that they missed all the signals. While on the surface this may seem to be problematic, I argue that removing them actually improves the quality of the data for statistical analysis.

In this study, the secondary probe appears at a random interval with at least 30 seconds between signals. Each signal remains on the screen for five seconds (5000ms) for the participants to respond. If the participant does not respond within the five seconds, the server records the response as a missing data. In other words, the fully attentive participants represent extreme outliers who were at least eight standard deviations away from the mean. Even if I could distinguish them from the uncooperative participants, including them in the analysis would create a peak on the higher end and distort the mean. Moreover, that peak is not an accurate measurement of attention because any response time longer than 5000ms to 30000ms and above were lumped together with no variance between them. Therefore I argue that removing the 17 cases of non-response to secondary task improved the study by 1) removing noise from uncooperative participants; 2) removing extreme outliers that are at least eight standard deviations away from the mean; 3) allowing me to have a clearer interpretation of STRT as a measurement of attention to primary task.

As a result, the sample used in the following analyses for testing the hypotheses consisted of 146 participants. The participants were randomly distributed among the three conditions, with 49 participants in the no-scaffolding condition, 52 participants in the gaming-skill scaffolding condition, and 45 in the content-knowledge scaffolding condition.

In order to ensure group equivalence among the independent and control variables, one-way Analysis of Variance (ANOVA) was performed between the three induced scaffolding conditions on working memory capacity, gaming-skill expertise, political involvement, and content knowledge expertise. The ANOVA results showed no significant difference between the condition on the main independent variables--working memory capacity (F [2, 142] =.81, *n. s.*), and gaming-skill expertise (F [2, 143] =.99, *n. s.*). There was also no significant difference between the conditions on the control variables—political involvement (F [2, 133] =.86, *n. s.*), and content-knowledge expertise (F [2, 143] =.08, *n. s.*). The ANOVA result indicates that the three scaffolding groups were equivalent among the main independent variables and control variables.

Hypotheses Testing

Hypotheses 1 and 2 posited that because working memory capacity and gaming-skill expertise are more likely to be significant in complex tasks that that demand more attention control. Therefore working memory capacity and gaming-skill expertise will positively predict more attention (i.e. slower STRT) in the no-scaffolding condition.

A hierarchical multiple regression analysis was conducted to examine the hypotheses 1 and 2 under the no-scaffolding condition (n=49). Prior political involvement and content knowledge were entered in the first block as control variables. The mean-centered AOSPAN score and mean-centered gaming-skill expertise score were entered into the second block as independent variables; the interaction term between AOSPAN and gaming-skill expertise was entered into the third block to test interaction effect between working memory capacity and gaming-skill expertise. Attention measured by STRT was entered as the dependant variable.

Under the no-scaffolding condition, the analysis result showed that that the overall model was not significant, F (5, 37) =.46, *n. s.*. There was no main effect for neither working memory capacity (β=.33, *n. s.*) nor gaming-skill expertise (β=.19, *n. s.*). There was also no interaction effect between working memory capacity and gaming skill expertise on attention (β=-.31, *n. s.*). The regression results are shown in Table 2. The results were not consistent with hypotheses 1 and 2. Differences in working memory capacity and gaming skill expertise did not predict attention in the no-scaffolding condition which was expected to be the most demanding on working memory.

Table 2 Regression analysis of working memory capacity and gaming expertise on attention in no-scaffolding condition

	B	**β**	**t**	**p**
(Intercept)	1104.43		7.22	<.001***
Content knowledge	-31.43	-.18	-1.13	.134
Political experience	-17.60	-.05	-.31	.380
(Intercept)	1119.21		7.09	<.001***
Content knowledge	-29.18	-.17	-.99	.164
Political experience	-26.31	-.07	-.44	.331
Working memory capacity (WMC)	9.40	.12	.69	.247
Gaming-skill expertise (GE)	-3.99	-.02	-.14	.447
ΔR^2=.01				
(Intercept)	1131.07		7.03	<.001***
Content knowledge	-26.96	-.15	-.90	.187
Political experience	-30.56	-.09	-.50	.309
Working memory capacity (WMC)	26.25	.11	.76	.228
Gaming-skill expertise (GSE)	24.08	-.03	.40	.348
Interaction (WMC x GSE)	-4.94	-.09	-.53	.301
ΔR^2**<.01**				

*<.05, **<.01, ***<.001.

Hypothesis 3 posits that because experts differ from novices in that they can draw on existing schema from their long-term memory to process familiar information in chunks. Expertise is more likely to be a significant predictor of attention when the task is recognized as a familiar task. Therefore gaming skill expertise will positively predict attention in the gaming-skill scaffolding condition which resembles a typical game design setup. Another hierarchical multiple regression analysis was conducted to examine hypothesis 3, this time under the gaming-skill scaffolding condition (n=52). Prior political involvement and content knowledge were entered in the first block as control variables. The mean-centered AOSPAN score and mean-centered gaming-skill expertise score were entered into the second block as independent variables; the interaction term between AOSPAN and gaming-skill expertise was entered into the third block to test interaction effect between working memory capacity and gaming-skill expertise. Attention measured by STRT was entered as the dependent variable.

Under the gaming-skill scaffolding condition, the analysis result showed that the overall model was significant, *F* (5, 37) = 2.47, *p*<.05, *Adj.* R^2= .15. There was no main effect for working memory capacity (β=.34, *n. s.*). However there was significant main effect for gaming-skill expertise (β=.77, *p*<.01). There was also significant interaction effect between working memory capacity and gaming skill expertise on attention (β=-.89, *p*<.05). See Table 3 for the regression analysis results. The result was consistent with hypothesis 3 and hypothesis 4; players with higher gaming expertise allocated more of their attention to processing the game information when the game design matched the familiar pattern of having controls and basic navigation presented before the complex narrative and educational messages. The significant interaction effect indicates that participants with higher gaming-skill expertise and lower working memory capacity paid more attention to playing the game and responded slower to the secondary probe.

Table 3 Regression analysis of working memory capacity and gaming expertise on attention in gaming-skill scaffolding condition

	B	**β**	**t**	**p**
(Intercept)	1170.26		4.89	<.001***
Content knowledge	29.71	.08	.48	.316
Political experience	-28.80	-.06	-.35	.365
(Intercept)	1144.57		4.95	<.001***
Content knowledge	45.07	.11	.76	.225
Political experience	-33.86	-.07	-.41	.342
Working memory capacity (WMC)	-37.11	-.27	-1.74	.045*
Gaming-skill expertise (GE)	108.89	.34	2.21	.016*
ΔR^2=.15				
(Intercept)	1201.32		5.40	<.001***

Table 3(cont'd)

Content knowledge	15.18	.04	.26	.398
Political experience	-8.20	-.02	-.10	.459
Working memory capacity (WMC)	46.12	.34	1.06	.149
Gaming-skill expertise (GSE)	241.88	.77	3.11	.002**
Interaction (WMC x GSE)	-25.65	-.89	-2.15	.019*
$\boldsymbol{\Delta R^2}$=.09				

*<.05, **<.01, ***<.001.

Hypotheses 5a and 5b are based on the expertise-reversal effect. Experts consider scaffolding as redundant information that they cannot avoid. Therefore experts will have to use more working memory in order to process the redundant information (slower STRT) in the scaffolding conditions than without scaffolding.

Before testing these hypotheses, a median split was performed on gaming-skill expertise (median=3.50) to categorize the participants into gaming *experts* (n=67) and *non-experts* (n=79). An Analysis of Covariance (ANCOVA) was conducted among the gaming experts group (n=67) to test the hypotheses. The three scaffolding conditions were entered as the independent variable. Working memory capacity, content-knowledge, and political involvement were controlled as covariates. The analysis result showed that there was significant difference between the three scaffolding conditions in attention scores measured by STRT, F (2, 52) =3.74, <.05, partial η^2=.13. Participants in the gaming expert group's attention was highest in the game-skill scaffolding condition (M=1392.78, SD=759.38), followed by the content-knowledge scaffolding condition (M=1040.00, SD=279.57). The expert group's attention was lowest in the no-scaffolding condition (M=1007.59, SD= 293.26). See Table 4 for the ANCOVA analysis result.

Table 4 ANCOVA comparison of attention between scaffolding conditions

	df	**F**	**partial η^2**	**p**
(Intercept)	1	37.24	.42	<.001***
Working memory capacity	1	3.89	.07	.054
Content knowledge	1	10.8	.02	.304
Political involvement	1	.07	<.001	.790
Scaffolding Conditions	2	3.74	.13	.030*

*<.05, **<.01, ***<.001

A post-hoc comparison using Bonferroni test was conducted to determine the source of the significance. The analysis result showed that there was significant difference between the game-skill scaffolding condition and the no-scaffolding condition (p<.05). However, there was no significant difference between the content-knowledge scaffolding condition and the no-scaffolding condition (*n. s.*). The analysis results were consistent with hypothesis 5a that participants with higher gaming-skill expertise were more attentive (i.e. used more working memory) in the gaming-skill scaffolding condition than in the no-scaffolding condition. However the result was not consistent with hypothesis 5b, higher-gaming expertise participants did not allocate more working memory in the content-knowledge scaffolding condition than the no-scaffolding condition.

The expertise-reversal effect argued that experts would comprehend more of the educational content in the no-scaffolding condition without the redundant information caused by scaffolding. Therefore hypothesis 6 posited that participants with higher gaming-skill expertise would have the highest comprehension score in the no-scaffolding condition in comparison to the two scaffolding conditions. An ANOVA analysis with the three scaffolding conditions as IV and comprehension as DV was performed on the expert group (n=67) categorized by performing a median split on gaming-skill expertise. The analysis result was not consistent with the hypothesis. There was no significant difference in comprehension scores between the three conditions for the expert group, *F* (2, 64) =.41, *n. s*. Even though comprehension in the no-scaffolding condition (*M*=5.25, *SD*=2.31) was marginally higher than the gaming-skill scaffolding condition (*M*=4.89, *SD*=2.66), the difference was not statistically significant. It was the content-knowledge scaffolding condition which had the highest comprehension score (*M*=5.58, *SD*=2.52), but the difference in comparison the other two condition were not significant either.

The expertise reversal effect argued that reducing unnecessary redundant information which increases working memory demand is better for expert learners. However, the reverse cohesion effect posits that more active processing may actually improve comprehension. The first research question (RQ1) in this study seeks to examine whether more or less attention to the game leads to more comprehension in the context of learning from *the ReDistricting game*. Two separate hierarchical regressions were conducted on the gaming-skill expert and non-expert groups. Working memory capacity, content knowledge, and political involvement were entered in the first block as control variables; attention (measured by STRT) was entered as the IV. And comprehension score was entered as DV.

In the non-expert group (n=79), the overall regression model was significant, F (4, 66) =3.07, p<.05, *Adj.* R^2=.12. The analysis results showed that working memory capacity was a significant predictor of comprehension (β=.26, p<.05). Attention was positively correlated to comprehension but only close to significant (β=.21, p=.054). See table 5 for regression analysis results. The results indicate that for learners with lower gaming-skill expertise, working memory capacity positively predicted comprehension.

Table 5 Regression analysis of attention on comprehension (non-expert group)

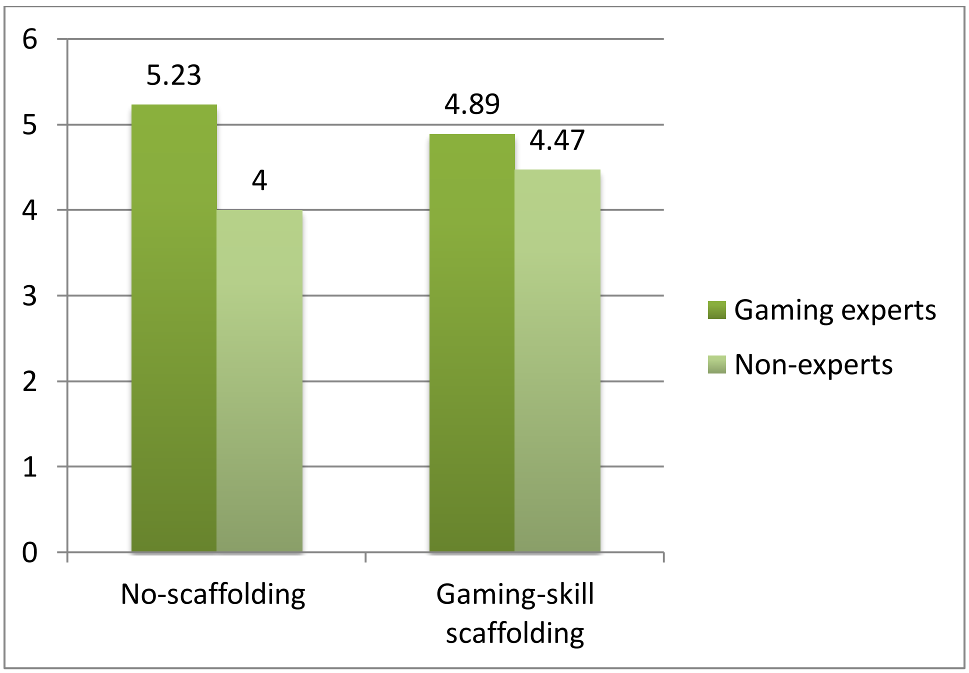
	B	**β**	**t**	**p**
(Intercept)	2.35		2.77	<.01**
Content knowledge	.11	.08	.62	.266
Political experience	.38	.26	1.25	.109
Working memory capacity (WMC)	.17	.29	2.29	.013*
(Intercept)	.75		.58	.282
Content knowledge	.18	.13	1.01	.159
Political experience	.43	.18	1.44	.077
Working memory capacity (WMC)	.15	.26	2.03	.024*
Attention	.001	.21	1.63	.054
$\boldsymbol{\Delta R^2}$=.04				

*<.05, **<.01, ***<.001

In the expert group (n=67), the overall regression model was not significant, F (4, 53) = 1.43, *SD*=.24, *Adj.* R^2=.03. None of the variables were significant predictors of comprehension. Which suggest that for gaming-skill experts, neither working memory capacity nor attention predicted comprehension.

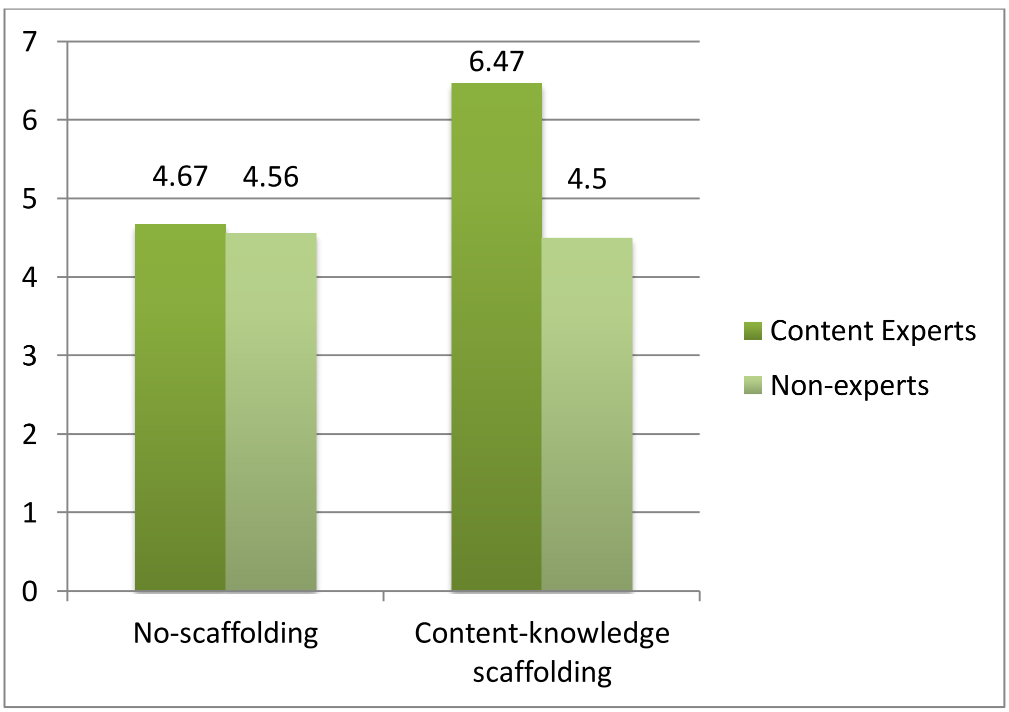
So far the study has been largely focused on learners with higher gaming expertise. Research question 2 seeks to examine whether gaming-skill scaffolding design mitigated the difference between gaming-skill expert and non-expert to improve comprehension for the participants with lower gaming-skill expertise. A one-way ANOVA was conducted to compare comprehension of gaming-skill experts and non-experts between the gaming-skill scaffolding condition and the no-scaffolding condition. The result showed that while in the no-scaffolding condition, there was significant difference (F [1, 47] = 4.08. p<.05) between gaming-skill experts (M=5.25, SD=2.31) and non-experts (M=4.00, SD=2.03). The significant difference became insignificant in the gaming-skill scaffolding condition, F (1, 49) =.43, *n. s*. Participants with higher gaming-skill expertise (M=4.89, SD=2.66) did not perform significantly better than participants with lower gaming-skill expertise (*M*=4.47, *SD*=1.97). Comparison of the results is shown in Figure 2. In other words, the difference between gaming-skill experts and non-experts were mitigated by the gaming-skill scaffolding design.

Figure 2 The effect of gaming-skill scaffolding on comprehension



Research Question 3 seeks to examine if content-knowledge scaffolding design would improve comprehension for the participants with lower content-knowledge expertise and mitigate the difference between participants with higher and lower content knowledge expertise. A median split was performed on content-knowledge (median=2.00) to categorize the participants into *content experts* (*n*=71) and *non-experts* (*n*=75). Note that since content-knowledge expertise is skewed towards the lower end, this categorization is only comparing *relative content expertise* rather than actual content expertise. A one-way ANOVA was conducted to compare comprehension of content experts and non-experts between the content-knowledge scaffolding condition and the no-scaffolding condition. The result showed that in the no-scaffolding condition, there was no significant difference (F [1, 47] = .03. *n.s.*) between content experts (M=4.67, SD=2.63) and non-experts (M=4.56, SD=1.83). However, there was significant difference between content experts (M=6.47, SD=2.22) and non-experts (M=4.50, SD=2.32) in the content-knowledge scaffolding condition, F (1, 43) =8.24, p<.01. Comparison of the results is shown in Figure 3. The results indicate that instead of mitigating the difference between content experts and non-experts, content-knowledge scaffolding seems to largely improve comprehension of the participant who had relatively higher content knowledge in the first place.

Figure 3 The effect of content-knowledge scaffolding on comprehension



Additional Results: Changes in Perceived Knowledge and Problem Severity

Since one of the two main goals of *the ReDistricting game* was to communicate the problems of redistricting to players, two additional analyses were conducted to examine 1) whether participants felt they had gained knowledge of redistricting after playing *the ReDistricting game*, and 2) whether there was change in their perceived severity of the problems associated with redistricting after playing *the ReDistricting game*.

Two sets of pre-test and post-test repeated measures were used to examine these questions. The participants answered the question "How much do you know about redistricting?" on a 7-point scale with 1=extremely little knowledge and 7=extremely knowledgeable. And the question "Do you think the current redistricting process is…" on a 7-point scale with 1= Not problematic at all, and 7=extremely problematic. The mean and standard deviation scores are shown in Table 6

Table 6 Changes in perceived knowledge and perceived problem after playing the game

	Scaffolding Conditions		
	No-scaffolding	**Gaming-skill scaffolding**	**Content-knowledge scaffolding**
Pre-game knowledge	3.94 (1.51)	2.83 (1.59)	2.82 (1.89)
Post-game knowledge	3.16 (1.84)	3.61 (1.78)	3.53 (1.95)
Δ perceived knowledge	-.78	.78*	.71*
Pre-game perceived problem	3.49 (1.00)	3.54 (1.15)	3.53 (1.12)
Post-game perceived problem	2.49 (1.37)	2.75 (1.70)	2.24 (1.25)
Δ perceived problem	-1.00***	-.79**	-1.29***

*<.05, **<.01, ***<.001

Three repeated-measures ANOVA were conducted to determine if the changes in self-reported knowledge were significant before and after playing *the ReDistricting game*. The results showed that in the no-scaffolding condition, there was no significant change of self-reported knowledge after playing the game, Wilk's Lamda=.99, F (1, 48) =.64, *n. s*. However, in the gaming-skill scaffolding condition, there was a significant increase of self-reported knowledge after playing the game, Wilk's Lamda=.89, F (1, 50) =6.06, p<.05. There was also a significant increase in the content-knowledge scaffolding condition, Wilk's Lamda=.87, F (1, 44) =6.62, p<.05. The analyses results indicate that when playing under the no-scaffolding condition, participants did not think they have gained knowledge about redistricting. But when playing under the gaming-skill scaffolding or the content-knowledge scaffolding condition, participants believed that their knowledge about redistricting improved.

Three other repeated-measures ANOVA with were conducted to determine if the changes in perceived problem severity were significant before and after playing *the ReDistricting game*. The results showed that in the no-scaffolding condition, there was significant decrease of perceived problem severity after playing the game, Wilk's Lamda=.74, F (1, 48) =16.56, p<.001 In the gaming-skill scaffolding condition, there was a significant decrease of perceived problem severity after playing the game, Wilk's Lamda=.86, F (1, 50)=8.41, p<.01. There was also a significant decrease in the content-knowledge scaffolding condition, Wilk's Lamda=.52, F (1, 44) =40.49, p<.001. Surprisingly, instead of increasing participant's awareness about the problems of redistricting, the experience of playing *the ReDistricting game* decreased the participant's perceived severity about the problems of redistricting.

Chapter 6

Discussion

Summary and Discussion of Findings

Hypotheses 1 and 2 were not supported as working memory capacity and gaming-skill expertise did not predict attention in the most difficult condition--the no-scaffolding condition. Hypothesis 3 was supported, gaming-skill expertise positively predicted attention in the gaming-scaffolding condition which resembles the conventional level design. Hypothesis 4 was also supported as there was a significant interaction effect between working memory capacity and gaming skill expertise on attention in the gaming-skill scaffolding condition. Hypotheses 5a and 5b were hypotheses based on the expertise reversal effect and reverse cohesion effect. Hypothesis 5a was supported as gaming experts paid more attention to the gaming-scaffolding condition in comparison to the other two conditions. However, hypothesis 5b was not supported. Hypothesis 6 sought to test the predictions of the expertise reversal effect, in which experts would comprehend more in the no-scaffolding condition, this hypothesis was not supported.

Research question 1 asked whether working memory capacity and attention to the game predicted comprehension. The results showed that for experts, working memory capacity and attention to game did not predict better attention. However, for non-experts, working memory capacity was a significant predictor of comprehension, and attention to game was close to significance. Research questions 2 and 3 asked whether gaming-skill scaffolding and content-knowledge scaffolding mitigated the gap between experts (gaming skill and content knowledge) and non-experts. The results showed that gaming-skill scaffolding was effective in mitigating the gap between gaming experts and non-experts, but content-knowledge scaffolding widened the gap between content experts and non-experts.

Working Memory, Gaming-Skill Expertise, and Attention

This study sought to investigate how working memory capacity and gaming-skill expertise interact with digital game scaffolding design to influence attention and comprehension in the context of playing a digital game for learning.

Prior studies on digital game based learning have suggested that digital games communicate with learner in multimedia environments via problem-solving experiences. The learners' limited working memory capacity is involved in processing the combination of visual, auditory information, along with the navigation requirements, and problem-solving experiences. Therefore, it has been suggested that learners' working memory capacity may interact with different instructional design to influence attention and how well learners can learn from digital games (e.g., Kiili, 2005). Hypotheses 1 and 2 of this study are based on the assumption that the effect of individual differences in working memory capacity and gaming-skill expertise on attention to the game would be significant when the task is more complex and requires more attention control (Kane & Engle, 2003). Surprisingly, the analysis result was not consistent with these two hypotheses. Working memory capacity and gaming-skill expertise were not significant predictors of attention in the no-scaffolding condition.

One potential explanation for this result is that the working memory demand of *the ReDistricting game* exceeds that of the participants in this study. When participants were asked to rate the difficulty of Mission 2 (advanced) on a 7-point scale after the game, the mean score under the no-scaffolding condition was 5.12 (*SD*=1.98). This result suggests that participants in the no-scaffolding condition perceived the game as difficult. Individual differences in working memory capacity and expertise would be most significant if the working memory demand of the task falls within the working memory capacity distributions of the participants. If the task is too easy, we would not observe variations because most participants would be able to perform the task without tapping their working memory limits. Similarly, if the task is too difficult, we would not observe variations because most participants would suffer from cognitive overload and could not perform the task. Going back to the staring contest analogy described in the literature review section, if the staring contest was too demanding and ran for 60 seconds, both contestant A who can stare for 50 seconds and contestant B who can stare for 20 seconds would fail and we would observe no significant difference.

Most prior studies on individual differences in working memory capacity and expertise have used relatively simple tasks such as the Stroop test (Kane & Engle, 2003) or proactive-inference test (Engle & Kane, 2000). When using simple tasks, it is less likely that the working memory demands of the tasks would exceed the participants' capacity. But in a complex problem-solving experience such as digital game based learning, working memory is involved in a number of information processing such as visual-spatial navigation, perceptual motor skills, accurate timing of responses, as well as short and long-term strategic decisions (Logie et al., 1989). Therefore it becomes more likely for complex cognitive tasks to overload the learners' capacity. When the learners suffer from cognitive overload, they may have slower reaction time and large number of missed response to secondary probes. But they may also respond by giving up on the primary task (playing and processing the game), and switch their attention to reacting to the secondary probe, thus instead of longer reaction time, they will have shorter reaction time. When the task may be too complex and demanding to the participants, additional measures of attention should be applied to cross reference with STRT results.

The third hypothesis is based on the theory and findings that show expert performance is determined by the ability to identify a task as within one's existing schema, and the ability to retrieve matching mental representations and solutions stored within one's long-term memory (e.g., Chase & Simon, 1973). When experts cannot recognize the task as within their expertise domain, or cannot retrieved matching information from their long-term memory, they are likely to process the task and information in the same way as non-experts and have no advantage. Therefore the study hypothesized that gaming-skill expertise is more likely to be a significant predictor of attention when the game is recognized as a familiar task and learners with higher gaming-skill expertise will actively search and process goal-related information from the game and within their long-term memory. The analysis result was consistent with hypothesis 3, gaming-skill expertise positively predicted attention to the game in the gaming-scaffolding condition. The finding indicates that when the conventional level-design is applied to support learners by introducing them to the basic controls and narratives first, learners who have higher gaming-skill expertise are more likely to recognize the task as within their expertise domain, and allocate more attention resources (i.e. working memory) to processing information from the game and retrieving mental representations from their schema.

Gaming-skill expertise also interacted with the learners' working memory capacity to affect attention. In other words, learners with lower working memory capacity and higher gaming-skill expertise allocated more attention resources to the game. This finding is not surprising because according to theory, working memory capacity should be negatively correlated with STRT. Learners with higher working memory capacity would react faster to secondary probes because they have more available working memory, while learners with lower working memory capacity would react slower to secondary probes because they have less available working memory.

Another way of interpreting the result of hypothesis 3 is that the game-skill scaffolding condition is considered a more "cohesive" text, especially to learners with higher gaming skill expertise. Text cohesion is relative to the learners' expertise level. A cohesive text is one in which all the relevant information are included in a coherent way to the learner. In contrast, an incohesive text is one that requires learners to draw upon existing expertise to make inference between information and maintain coherence (Oakhill, Cain, & Bryant, 2003; Ozuru, Dempsey, & McNamara, 2007). Note that the majority of participants in this study had low content knowledge about the redistricting process (M=2.86, SD=1.65). Those who had higher gaming-skill expertise were able to see the design structure of the gaming-scaffolding condition as a more cohesive text that included the relevant information for navigating and understanding the game, whereas the learners with lower gaming-skill expertise could not. Consequently, in accordance to the findings by O'Reilly and McNamara (2007), learners with low content knowledge only benefitted from cohesive text (i.e. the gaming-skill scaffolding condition) when they had sufficient gaming-skill expertise. In other words, gaming-skill expertise can help learners with lower content expertise improve attention to information processing, but only when the game's design matches the schema about digital games stored in the learners' memory.

Looking back at the non-significant result of hypotheses 1 and 2 in the no-scaffolding condition, an alternative explanation is that without introducing the controls, narrative, and problem goals in a coherent order, even the learners who had relatively higher gaming-skill expertise could not recognize the game as a cohesive text and did not benefit from their expertise. This is similar to the study on chess masters by Chase and Simon (1973). The chess master's superior memory performance disappeared when a random set of chess pieces were given. When the chess masters cannot recognize the patterns in front of them and find matching patterns from their long-term memory to help them process the information; they are forced to forgo any expert strategies and processing each individual chess piece just as a novice would. In general, gaming-skill expertise cannot facilitate attention if the game was not designed or introduced in a recognizable way for learners with higher gaming-skill expertise to apply their schema and expert strategies.

Expertise-Reversal Effect, Scaffolding, and Comprehension

Hypotheses 4a and 4b were based on the arguments by Kalyuga et al. (2000, 2003) that scaffolding induces higher working memory demands on experts because of the introduced redundant information. The analyses results showed that indeed, gaming-skill experts paid more attention (slower STRT) to the gaming-skill scaffolding condition than the no-scaffolding condition. There was no significant difference between the content-knowledge scaffolding condition and the no-scaffolding condition. This finding was consistent with hypothesis 4a derived from Kalyuga et al. (2000, 2003).

However, contrary to Kalyuga et al.'s (2003) interpretations, study findings that show experts increased working memory load in the scaffolding condition does not necessarily disconfirm McNamara's arguments about the reverse-cohesion effect. Kalyuga et al.'s (2003) definition of experts did not separate content-knowledge expertise and skill expertise, while McNamara's reverse-cohesion effect was strictly predicting a reversal for experts with higher content-knowledge expertise, not skill expertise. In fact, McNamara's more recent study showed that when learners possess higher skills to process the text, both learners with higher and lower content-knowledge expertise benefitted from having cohesive text (Ozuro, Dempsey, & McNamara, 2007). Therefore, the findings in hypotheses 4 which showed gaming-skill experts had higher attention to the gaming-skill scaffolding condition can support both explanations provided by Kalyuga et al. (2003) and McNamara (2001). Gaming-skill scaffolding may have introduced redundant information for learners with higher gaming-skill scaffolding, but at the same time the redundant information helped them identify the task as a cohesive text and retrieve related information from their schema. The increased attention may be partly attributed to processing the additional information, and partly attributed to retrieval of related information from the learners' long-term memory.

The result of hypothesis 4 focusing on attention did not tease apart the two explanations. Hypothesis 5 seeks to compare the two explanations by examining comprehension. Kalyuga et al. (2003) argued that redundant information is harmful to experts; therefore gaming-skill experts would have higher comprehension in the no-scaffolding condition than the two scaffolding conditions. On the other hand, McNamara et al. (Ozuru, Dempsey, & McNamara, 2007) argued that learners with higher skill expertise would have higher comprehension in the cohesive condition, that is, the gaming-skill scaffolding condition in this study. Unfortunately, the results neither confirmed nor disconfirmed either explanation as there was no significant difference in comprehension scores for gaming-skill experts between the three conditions. This result along with the previous findings seem to suggest that while gaming-skill experts allocated more attention to the gaming-scaffolding condition, the increased attention did not translate into higher or lower comprehension in comparison to the other two conditions.

However, this does not suggest that increased attention for experts is not associated with comprehension. The relationship between expert attention and comprehension depends on the game's design, or according to Fisch's (2000) model, the *distance* between narratives and educational content. I argued that in *the ReDistricting game*, because the educational content is opposite of the game's explicit goals and mechanics, therefore when the expert gamers quickly identified the game as within their expertise domain, they may have focused their attention on the game's explicit goal and mechanics, and blocked out *irrelevant* information which are important to comprehension but not to reaching the game's goal. It is possible that in a game which has a short distance between narrative and educational content, or that the narrative *is* the educational content, increased expert attention may improve comprehension.

The expertise reversal effect is based on the assumption that reducing unnecessary redundant scaffolding which increases working memory demand benefits expert learners. However, the reverse cohesion effect posits that more active processing may actually improve comprehension. The first research question that this study posed was "will attention to the game positively or negatively predict comprehension?" This is not an easy question to answer and the answer is determined by both learner characteristics and the game's design. The analysis result showed that consistent with the previous finding, for learners with higher gaming skill expertise, attention to the game was not a significant predictor of comprehension.

However, when examining learners with lower gaming-skill expertise, working memory capacity was a significant predictor of comprehension, and attention to game was close to significance (p=.054). The results suggest that the gaming-skill experts and non-experts may be paying attention to different aspects of the digital game based learning experience. While STRT tells us how much working memory is allocated to the game, it cannot differentiate between learning-related attention and extraneous attention that is not related to comprehension. It is possible that when gaming-skill experts allocate more attention, they are focusing on more goal-related information. And when non-experts allocate more attention, they are processing all the information equally without distinction. According to Fisch's capacity theory of comprehension from educational media (Fisch, 2000), when the distance between the narrative and the educational content is large, working memory allocated to processing the narrative competes with working memory allocated to processing the educational content. Such might be the case with *the ReDistricting game*. *The ReDistricting game* adopts a reverse role-playing narrative in which the player plays as the problem source, and the intended message is the opposite of the game's overt goals. In this case, it is likely that gaming-skill experts focused on achieving the game's overt goals, and processed information that may aide them in reaching that goal while blocking out "irrelevant" information as interference. However, since that goal is not the intended educational message, attention to goal-related information does not predict more comprehension. In comparison, non-experts do not have gaming schema to help them identify what is goal-related information and unrelated information, they are more likely process a larger set of information. And because non-experts do not have existing mental representations from previous game experiences, they need to use the information from this game to construct their mental representation, which may sometimes lead to more comprehension of the intended message.

This explanation is further supported by the additional analyses results, while both gaming-skill experts and non-experts believe to have gained knowledge after playing *the ReDistricting game,* their perceived severity about the problems of redistricting reduced instead of increased. The reverse role-playing plus the higher difficulty may have misled some participants to conclude that the game is a demonstration of how difficult it is to manipulate elections through redistricting. Many participants in the study responded in to the open-ended comprehension questions with frustration over how difficult it is to redistrict.

> "*[T]he redistricting process is tedious and someone will always be unhappy when their district is being cut into by another. It is incredibly difficult to make the districts completely fair for both parties and all candidates*."—Participant 11

> "*Honestly, I do not really know much. However, according to the game, the redistricting process can be kind of tedious and irritating. Pleasing everyone, at the same time was nerve wrecking*."—Participant 32

More about the theoretical and practical implications of the study will be discussed in the next chapter.

Scaffolding Design to Support Non-Experts

The last two research question in this study investigated whether gaming-skill scaffolding and content-knowledge scaffolding could improve comprehension of learners with lower gaming-skill expertise and content-knowledge expertise. In other words, does scaffolding help novices? The analysis results were very interesting. Gaming-skill scaffolding mitigated the difference in comprehension between gaming-skill experts and non-experts. But content-knowledge scaffolding widened the gap through supporting learners with relatively more content-knowledge expertise.

Note that gaming-skill scaffolding was intended to support novice gamers by improving their ability to navigate the game. Without gaming-skill scaffolding, learners with lower gaming-skill expertise are more likely to suffer from disorientation caused by the non-linear multimedia environment and therefore have lower comprehension (Scheiter & Gerjets, 2007). Through gaming-skill scaffolding, they should be able to gain expertise in navigating the game and searching for goal-related information, therefore the gap between gaming-skill experts and non-experts should narrow. This finding suggests that it is very important for educational games to provide some kind of skill-based support for learners with lower gaming-skill expertise.

Content-knowledge scaffolding was intended to support learners with lower content knowledge by providing an external framework for them to combine and interpret the game information. In some ways, it is like priming participants to focus on certain information. Note that in general, the participants in this study had low knowledge about the topic of scaffolding. Therefore the distinction between content experts and non-experts are only relatively high and low content-knowledge expertise. The actual difference between the two groups is very small. What was surprising is that instead of mitigating the gap between content-knowledge experts and non-experts, providing an explicit framework did not benefit the learners with relatively low content knowledge. Instead it benefitted those who had relatively more content knowledge at the beginning. This is similar to the rich-gets-richer effect in which the learners with scarce content knowledge are unable to make sense of the game even when the explicit framework was provided to them. But for learners with even a small amount of content knowledge, they were able to utilize the additional explicit framework and map their limited knowledge and new information on to that framework. As a result, their comprehension improved exponentially. This finding suggests that it is important for learners to have some basic knowledge about the content before they play educational digital games.

Limitations

Prior studies on the educational effects of digital game based learning have found mixed results. This study sought to investigate the mixed results through examining how individual differences in working memory capacity and gaming-skill expertise interact with game scaffolding designs to affect attention and comprehension. As with all empirical studies, this study is not without limitations.

First of all, the study measured gaming-skill expertise and content-knowledge expertise through self-reported measures. This was a trade-off decision made to avoid objective measurement and practice effect. While it may be better to obtain objective measures of gaming skills and content knowledge by administrating a test that require participants to play the game or answer questions that are closely related to the redistricting process. These tests are likely to prime participants to look for answers in the game, or confound the study by allowing them to practice. However, by using self-reported measures, the study may introduce social-desirability issues and other third variable effects. Luckily, through random assignment and test of group equivalence, the three groups seem to be equivalent and comparable.

Second, the results of this study are based on a single game--*the ReDistricting game*. The game was chosen because it was designed for undergraduate students and involves a topic undergraduate students are generally not familiar with. However, the generally low content knowledge restricted the study from testing how actual *content experts* may interact and process information within the three conditions. On the flip side, because the participants in this study were generally low on content knowledge expertise, they provided a relatively homogenous sample and allowed the study to examine the effects of working memory capacity and gaming-skill expertise while controlling for the interaction effects of content knowledge.

Third, while there has been a long tradition in psychology studies of using secondary task reaction time for measure working memory load and attention (e.g., Daneman & Carpenter, 1980); many of the studies have used relatively simple cognitive tasks in comparison to a complex problem-solving environment such as digital games. Findings from this study seem to suggest that there is qualitative difference in the information that learners with higher gaming-skill expertise and non-experts were focusing their attention on. STRT merely measures the *amount* of working memory allocated to the primary task, it cannot measure which aspect of the task were the participants processing? It also cannot distinguish between working memory allocated to processing external information and internal processing. However, it is important to remember that the construct of working memory is a theoretical construct and was not expected to map directly to areas in the brain or other biological measures (Baddeley, 2000). STRT may be used in combination to other measures of attention such as heart rate, eye-tracking, or server-based behavioral data to further determine whether there is indeed attention-focus difference between how gaming-skill experts and non-experts allocate their working memory to the game.

Fourth, the manipulation check indicated that while there was difference in complexity between the induced conditions, however even the lowest difficulty was rated as 4 on a 7-point scale. In other words, the study's manipulation did not create a single condition that was perceived as easy to the participants in this study. Instead, the comparison between the no-scaffolding condition and the gaming-skill scaffolding condition is a comparison of a difficult condition against a moderate difficulty condition. This may have caused hypotheses 1 and 2 to be non-significant, because the difficulty exceeded the participants' capacity, even for those who have higher working memory capacity and gaming-skill expertise. Without a condition that was considered easy, the study could not really examine McNamara's reverse-cohesion effect to see whether content-knowledge experts would engage in superficial information processing when they perceive the task to be too easy.

Fifth, the participants in this study only played *the ReDistricting game* for less than 30 minutes and could not replay multiple times or discuss the gameplay experience with other participants. This may have limited the effectiveness of the game in improving comprehension. However, this decision allowed the study to control for effects of repeated exposure to media and peer-learning, thus the results from this study are limited to self-directed learning through an educational digital game.

Sixth, the study results did not fully support neither the expertise-reversal effect nor the reverse-cohesion effect. It is possible that the manipulation of scaffolding in this experiment was not strong enough to observe the effects. To be more specific, the expertise reversal effect argues that the addition scaffolding information causes redundancy effect for expert learners and increase the amount of working memory demand, and even cognitive overload which hurts comprehension. The manipulation in this study may not have been strong enough to exceed the working memory capacity of the expert participants in this study, thus they were able to process the additional information without sacrificing their comprehension.

Chapter 7

Conclusion and Implications

Theoretical Implications

This study follows the line of research on expert performance and working memory (e.g., Hambrick & Engle, 2002) and extends the focus to investigate how working memory capacity and gaming-skill expertise influence attention and comprehension in the context of digital game based learning. Theoretically, the study adds to the large body of studies that show expertise as a strong predictor of attention on domain-specific information and complex cognitive tasks (Hambrick & Engle, 2002; McNamara, 2001). It also shows that among participants with lower gaming-skill expertise, working memory capacity was a significant predictor of comprehension in digital game based learning. Working memory capacity facilitated comprehension for novices because novices with higher working memory capacity were more capable of holding multiple information elements in their working memory and construct a mental representation of the problem. Consistent with findings from Hambrick and Engle (2002) the results from this study suggest that working memory capacity and gaming-skill expertise affect attention and comprehension as separate predictors. As a more general construct, working memory capacity may have affected comprehension through other variables. Gaming-skill expertise affected what information to focus on and how much working memory to allocate to the game.

The findings in the current study also suggest that there may be qualitative differences in how experts and novices allocate their attention. Due to the limitations of using STRT to measure attention, the current study cannot distinguish between attention allocation to different aspects of the game play and learning experience. However, previous studies have suggested that experts may be able to process procedural information automatically, which may sometimes benefit learning, but sometimes harm learning (Ricks, Turley-Ames, and Wiley, 2007). Automatic processing allows expert learners to free up more available working memory for processing other information, but it may also limit their attention to familiar information which matches their existing mental representations, while blocking out novel information that may be important but does not match their mental representation. For example, Ricks et al. (2007) used the Remote Associates Task to test whether experts and non-experts were able to detect questions designed to mislead experts into automatic processing and construct false answers. Their findings showed that when the task appeared to be within the experts' expertise domain, experts were likely to activate habitual processing and fail to detect that the automatically generated answer was incorrect. In comparison, because non-experts do not have existing mental representations to guide their inference, they were more likely to process the question cautiously and answer correctly. This finding suggest that in some cases, especially when the task design is complex and structurally similar to the experts' expertise domain, experts are more likely to make mistakes because they are quick to identify the task and process information with their existing schema, they do not consider alternative models and solutions.

However this does not imply that automatic habitual processing will always lead experts to overlook the educational contents. If the game's educational content is closely integrated with the game's mechanics, automatic processing by expert gamers may increase comprehension because they can understand and process the mechanics faster.

Overall, this study argues that any sweeping claim about the superior cognitive performance of experts or working memory capacity must be examined carefully. Based on the structure of the game and its narrative, sometimes the retrieval of exert schema may block out information that are relevant to learning. It is important for future studies to carefully consider how working memory capacity and gaming skill expertise may affect attention allocation, but also examine the structure of the game to determine if it is designed in a way that activates expert schema retrieval, and whether the retrieval of expert schema benefit or harms comprehension.

Practical and Design Implications

The study also has practical implications for practitioners and game designers of educational digital games. The study showed that many participants failed to comprehend the intended message of *the ReDistricting game* and instead constructed knowledge that was in the opposite direction. *The ReDistricting game* was designed using a common narrative used in educational and persuasive games—a reverse role playing perspective. While this type of narrative was intended to facilitate reflection and active knowledge construction, it should be used with caution. Instead of increasing their perceived severity about the problems of redistricting, the participants in the study decreased their perceived severity. This may be because the reverse role taking design first requires players to identify with the role and goals of the problem-source, and then reflect on their experience as a wrong-doing. Therefore in order to reach the goal, the learners actively identified with the source of the problem (e.g., the gerrymandering mapmaker). This reverse role-playing combined with the higher difficult may have depleted the learners' working memory capacity so that they did not have sufficient working memory for reflect and comprehend the intended narrative: that redistricting can be easily abused to undermine fair election. Instead, the high difficulty and reverse role-playing led participants to believe that the educational message was how difficult it was to redistrict and please political parties and the constituents.

However, this does not imply that *the ReDistricting game* or games that were designed using similar reverse role-playing perspectives are bad games. The fact that there was significant change in the perceived knowledge and problem severity indicate that playing the game was effective. However, when players play the game on their own, without a teacher or other guidance to help them make sense of the experience, this type of design may have unintended effects. The implication of this finding is that the reverse role-playing design should be used with caution and with guidance. A facilitator such as a teacher or an artificial tutoring agent could guild the players to reflect upon their experience and restructure their comprehension in the intended direction.

Another implication of this study is that digital game based learning should carefully balance the need to seek realistic simulations and game complexity. The advanced difficulty in *the ReDistricting game* was designed to be realistic and included the multiple conflicting goals of competing parties, the court, and legal constraints. However the multiple, sometime conflicting goals means that learner will have to hold the multiple goals in their working memory while making each decision. This inevitably increased the amount of working memory demand of playing this game. Under such high working memory demand, the players may not have sufficient working memory to reflect and understand the underlying message that the game intended to communicate. Educational game designers should make a careful decision about whether a realistic simulation is compatible to their intended effects. If the goal was to convey how redistricting could *easily* manipulate election results, then the game designer may want to consider removing some of the complexity (e.g., competing goals, multiple constraints, etc.) so not to overload the learners' working memory.

Another practical implication of this study is in the effect of skill or content scaffolding. The findings showed that gaming-skill scaffolding mitigated the difference between gaming-skill experts and non-experts. But the content-knowledge scaffolding widened the gap between content-knowledge experts and non-experts. The findings imply that gaming-skill expertise is an important factor affecting comprehension from digital games. Learners who have relatively low gaming skills are disadvantaged if no scaffolding is provided to them. Practitioners and game designers should implement scaffolding to support those who are less familiar with the media so that they do not become dysfunctional learners.

On the other hand, the findings suggest that content-knowledge scaffolding does not benefit those with scarce existing content expertise. But it significantly improved comprehension for learners with relatively more content expertise. This study suggest that self-directed learning with digital games such as the procedure in this study should not be used on learners who have almost no existing content knowledge. Instead, the practitioner and game designer should implement other techniques to increase existing content knowledge of the learners before they play. Once the learners have some basic understanding of the content, they are able to increase knowledge exponentially through minimal scaffolding and self-directed learning.

As a form of interactive medium, digital games have the potential to adapt to learner differences and tailor messages according to learner characteristics. This study is an early step in examining the effects of working memory capacity and gaming-skill expertise on attention and comprehension among different game scaffolding designs. Future studies should examine how to better measure attention and working memory allocation in complex learning environments such as digital games. It would also be worthwhile to examine different combination of scaffolding design to seek a design that would benefit both experts and non-experts.

APPENDICES

APPENDIX 1

Pre-test Questionnaire

Political Involvement (Kahne, Chi, & Middaugh, 2002)

How much do you agree or disagree that the following statements describes you?

[Strongly disagree=1 2 3 4 5 6 7=Strongly agree]

1. I often talk about politics and political issues.
2. I am interested in a career in politics and government
3. I often wear badges in support of certain political issues
4. I vote regularly
5. I often volunteer for political actions
6. I often post or forward political information to my friends
7. I often sign political petitions
8. I strongly support boycotting products that are against my political values
9. I often attend protests in support of my political values

Political Efficacy (American National Election Survey, 2011)

[Not at all=1 2 3 4 5 6 7=A great deal]

10. How much do government officials care what people like you think?
11. How much can people like you affect what the government does?
12. Do you believe people like you can change the government's decision?

Political Beliefs

How much do you agree or disagree with the following statements?

[Strongly disagree=1 2 3 4 5 6 7=Strongly agree]

13. Every citizen should have equal rights to vote.
14. Fair competition between candidates is crucial to a democratic election.
15. The current election system can be easily manipulated by people who holds power
16. Voters should decide who wins an election

ReDistricting Knowledge

[Strongly disagree=1 2 3 4 5 6 7=Strongly agree]

17. I am very familiar with the redistricting process
18. I consider myself an expert in how gerrymandering works.

Game Familiarity

On an average week, how many hours do you play the following digital game genres (on any device)?

[Not at all=1; 0 to 1hours=2; more than 1 hours, less than 2 hours=3; more than 2 hours, less than 3 hours=4; more than 3 hours, less than 4 hours=5; more than 4 hours, less than 5 hours=6; more than 5 hours=7]

19. First-person shooter (e.g., Call of Duty, Battlefield, Team Fortress, etc…)
20. Strategy (e.g., Civilization, StarCraft, tower defense, etc…)
21. Puzzle (e.g., Bejeweled, Bubble witch saga, Angry bird, etc…)
22. Simulation (e.g., SimCity, Sims, Farmville, Cityville, etc…)
23. Role-playing game: RPG (e.g., The Elder Scrolls: Skyrim, Diablo, Final Fantasy, etc…)
24. Sports (e.g., NBA 2K12, Madden NFL, racing, etc…)

25. Massively Multiplayer Online game: MMO (e.g., World of WarCraft, Star Wars: the old republic, etc…)
26. Action (e.g., Super Mario, Super Smash Bros, fighting games, platform games, etc.)
27. Music game (e.g., Guitar hero, Just Dance, etc…)
28. Board/ card digital games (e.g., Chess, Magic: the gathering, etc…)

How skilled are you with the following game genres?

[Not at all=1 2 3 4 5 6 7=Extremely skilled]

29. First-person shooter (e.g., Call of Duty, Battlefield, Team Fortress, etc…)
30. Strategy (e.g., Civilization, StarCraft, tower defense, etc…)
31. Puzzle (e.g., Bejeweled, Bubble witch saga, Angry bird, etc…)
32. Simulation (e.g., SimCity, Sims, Farmville, Cityville, etc…)
33. Role-playing game: RPG (e.g., The Elder Scrolls: Skyrim, Diablo, Final Fantasy, etc…)
34. Sports (e.g., NBA 2K12, Madden NFL, racing, etc…)
35. Massively Multiplayer Online game: MMO (e.g., World of WarCraft, Star Wars: the old republic, etc…)
36. Action (e.g., Super Mario, Super Smash Bros, fighting games, platform games, etc.)
37. Music game (e.g., Guitar hero, Just Dance, etc…)
38. Board/ card digital games (e.g., Chess, Magic: the gathering, etc…)

Game Effectiveness Questions

39. How much do you know about redistricting?

[Extremely little knowledge=1 2 3 4 5 6 7=extremely knowledgeable].

40. Do you think the current redistricting process is…?

[Not problematic at all=1 2 3 4 5 6 7=extremely problematic].

Appendix 2

Instructions for the stimuli

[No-Scaffolding condition]

First gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

A. Play through **Mission 2** on the **Advanced** difficulty for **5 minutes**. Pay attention to the game. You will be tested about the contents afterwards.

B. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

Second gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

A. Play through **Mission 2** on the **Advanced** difficulty **again**. Pay attention to the game. You will be tested about the contents afterwards.

B. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

[Gaming-skill scaffolding condition]

First gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

A. Play through **Mission 1** on the **Advanced** difficulty. Pay attention to the game. You will be tested about the contents afterwards.

B. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

Second gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

A. Play through **Mission 2** on the **Advanced** difficulty. Pay attention to the game. You will be tested about the contents afterwards.

B. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

[Content-knowledge scaffolding condition]

Content-knowledge scaffolding text

About the ReDistricting game

"Once you draw the district lines, you pretty much know who will win most races. And the amount of money spent on campaigns becomes nearly irrelevant. Most elections are over before they start."

— *Steven Mulroy, Former Attorney, U.S. Dept. of Justice*

On the same day last November that President Obama was reelected by a solid margin, his party's candidates for the House received about 1.5 million more votes collectively than the GOP's candidates. And yet when the new Congress convened, Republicans still enjoyed a solid majority in the lower chamber, with 235 seats.

The most popular explanation for this disparity involves gerrymandering—when one party uses its control of state government to redraw congressional district lines in a way that gives its candidates an electoral edge.

The Redistricting Game is designed to educate, engage, and empower citizens around the issue of political redistricting. Currently, the political system in most states allows the state legislators themselves to draw the lines. This system is subject to a wide range of abuses and manipulations that encourage incumbents to draw districts which protect their seats rather than risk an open contest.

By exploring how the system works, as well as how open it is to abuse, The Redistricting Game allows players to experience the realities of one of the most important (yet least understood) aspects of our political system. The game provides a basic introduction to the redistricting system, and allows players to explore the ways in which abuses can undermine the system.

First gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

C. Play through **Mission 1** on the **Advanced** difficulty. Pay attention to the game. You will be tested about the contents afterwards.

D. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

Second gameplay

PLEASE READ THE INSTRUCATIONS CAREFULLY.

C. Play through **Mission 2** on the **Advanced** difficulty. Pay attention to the game. You will be tested about the contents afterwards.

D. During the game play, you will see a **yellow box** appear randomly around the game. When you see it, **press SPACEBAR as fast as you can**. You will need to replay the game if you miss too many or is too slow on this task.

Appendix 3

Post-test questionnaire

Game Enjoyment

How much did you enjoy the game?

How pleasant do you feel about the game?

How fun do you feel about the game?

Difficulty and Efforts

How difficult was the game?

How much effort did you put into playing the game?

ReDistricting Knowledge

[Strongly disagree=1 2 3 4 5 6 7=Strongly agree]

1. I am very familiar with the redistricting process
2. I consider myself an expert in how gerrymandering works.
3. How much do you know about redistricting?

   [Extremely little knowledge=1 2 3 4 5 6 7=extremely knowledgeable].
4. Do you think the current redistricting process is…?

   [Not problematic at all=1 2 3 4 5 6 7=extremely problematic].

Free Recall

What are the potential problems with redistricting? (Describe as much detail as you can, including the principles of drawing election districts, and how it can be manipulated).

Cued-Recall Questions (Comprehension)

1) In the game, each election district must have____________ (number) of constituents.

   A. 650,000 - 660,000

   B. 640,000 - 650,000

   C. 630,000 - 640,000

   D. 620,000 - 630,000

   E. 610,000 – 620,000

2) From where did we get the term “Gerrymandering?”

   A. Elbridge Gerry, former governor of Massachusetts

   B. Geary Stohlt, colonial practice of reapportionment

   C. Gerry Minder, former director of the United States Census

   D. Aaron Mandering, former mayor of Atlanta, GA.

   E. Ronald Reagan, 40th President of the United States

3) What does “cracking” mean when it comes to redistricting?

   A. Carving off part of a district to create a new seat in Congress

   B. Unfairly under-representing poor neighborhoods

   C. Breaking up groups of similar voters

   D. All of the above

   E. None of the above

4) What does “packing” mean when it comes to redistricting?

A. Removing a district to oust the incumbent representative

B. Jamming one district with similar voters

C. Inflating the number of citizens in each district

D. All of the above

E. None of the above

5) ____________is a traditional standard that states election districts should not have jagged edges and skinny extensions.

A. Roundness principle

B. Contiguity principle

C. Compactness principle

D. All of the above

E. None of the above

6) What does partisan gerrymandering refer to?

A. Splitting election districts into smaller parts.

B. Moving one part of the election district to another district.

C. Changing the number of voters in each district.

D. Manipulating election districts to prevent competition between parties.

E. Manipulating election districts to favor one party over the others.

7) How does packing create partisan advantage for a specific party?

A. Cause wasted votes to opposing parties.

B. Cause inflated votes to opposing parties.

C. Compact votes to the supporting party.

D. Dilute votes to opposing parties.

E. Disperse votes to supporting party

8) Which of the following action is “illegal” in redistricting?

A. Cracking

B. Packing

C. Drawing disconnected districts

D. Drawing large districts over 12 square miles

E. Drawing small districts less than 2 square miles

9) How can redistricting be harmful to democratic elections?

A. Voters may have to vote in another district.

B. It can create unfair advantages for certain parties.

C. It can heighten competition between candidates.

D. All of the above.

E. None of the above.

10) Which of the following solutions can prevent gerrymandering

A. Establishing independent redistricting commissions in each state.

B. Use existing political districts such as state, county, or provincial lines.

C. Use a computer algorithm that only considers the shape of the state, the number of intended districts, and the population of each district.

D. All of the above

E. None of the above

11) The contiguity principle regulates that...

A. A single party's votes must be counted together

B. All the votes must be counted continuously

C. Contiguous districts must elect candidates from different parties

D. Each district must be one continuous shape

E. The governor's decision must be congruent to the state court's decision

Demographics

1. What year were you born in?
2. What is your gender? *[Female, Male, Others]*
3. What is your major?
4. How would you describe your political position? *[liberal, conservative, independent, others]*

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