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Solutions to Cognitive (Over)Load in Game-based Learning Using Learning Experience Design for K-12 Education: A Review of the Literature

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Solutions to Cognitive (Over)Load in Game-based Learning Using Learning Experience Design for K-12 Education: A Review of the Literature

by

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Report

Presented to the Faculty of the Graduate School of

The University of Texas at Austin

in Partial Fulfillment

of the Requirements

for the Degree of

Master of Arts

The University of Texas at Austin

May 2016

Dedication

To my family, my parents, James Wen, Mandy Xu, and my lovely friends.

Acknowledgements

I would like to express my deepest appreciation to all those who provided me the possibility to complete this report. I would like to give special gratitude to my advisors, Dr. Min Liu and Dr. Lucas Horton, whose contribution in stimulating suggestions and encouragement helped me complete this report.

My thanks and appreciations also go to my dad, mom, husband and friends who encouraged me to complete this impossible mission and people who willingly helped me out with their abilities. Thanks to all the people who have provided me with companion, support and encouragement.

Abstract

Solutions to Cognitive (Over)Load in Game-based Learning Using Learning Experience Design for K-12 Education: A Review of the Literature

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Abstract: Learners especially in K-12 education often encounter learning difficulties in the context of game-based learning. One explanation accounting for such learning difficulties in game-based environments is that cognitive load is not properly managed and overload is imposed on learners' working memory. Learning Experience Design (LX Design), as an ideal substitute compared to instructional design, has been growing to meet the requirements of game-based learning in the 21st century. Based on the development of game-based learning, various factors (e.g., content and functionality) should be weighed to facilitate an optimal learning experience. This report reviews the literature on the impact of cognitive (over)load on game-based learning based on Cognitive Load Theory (CLT). The report applies one specific User Experience Design (UX Design) model, Garrett's Elements (Garrett, 2011) to explain how LX Design can provide solutions to learning difficulties caused by cognitive (over)load. The purpose of this report is to conduct a review of literature including empirical studies and theoretical articles from 2007 to present. The findings showed that meaningful learning experience designs for game-based learning, in which three types of cognitive load (i.e., intrinsic, extraneous and germane cognitive load) play an important role, should integrate game design with instructional design principles.

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Chapter 1: Introduction

In recent eras, gaming has grown in popularity and become a defining characteristic of young learners (Sadera, Li, Song, & Liu, 2014). The design of a learning environment built on the educational properties of games can be an effective way to improve learning (Gros, 2007). Traditional instructional design (ID) identifies methods of instruction to support and facilitate learning (Reigeluth, 1999). A move from traditional instructional design approaches to learner-centered design practices thus reflects a philosophical shift from behaviorism to constructivism with regards to learning design (Dong, Chen, & Hernandez, 2015). Some commercial and custom-made educational games have been used in K-12 classrooms across the world to enhance students' learning experience (Wastiau, Kearney, & Van den Berghe, 2009). A large part of this popularity is motivated by the frustration with the current education system and a desire for alternative ways of teaching and learning (Shute & Kim, 2011). However, how educational games can facilitate learning has become the next-generation question in K-12 education.

As the new application of games in the context of education, educational games have more distinctive meanings. According to de-Marcos, Garcia-Lopez and Garcia-Cabot (2016), a game is described as a system that presents a set of meaningful motivating challenges to the player. In their research, they found that game communities provide a virtual world where players can interact, and the game features help the players conceptualize the game environment and learning content. The prevalent issue encountered in educational games is whether their purpose is more educational than entertaining, or vice versa. Denis and Jouvelot (2005) coined the term *edutainment games* which they identified as games that follow a skill and drill format in which players either practice repetitive skills or rehearse memorized facts. Edutainment often fails in transmitting non trivial knowledge, repetitively calling the same action patterns and not throwing the learning curve into relief. In comparison, educational games require strategizing, hypothesis testing, or problem-solving, usually with higher order thinking rather than rote memorization or simple comprehension. Characteristics of educational games include:

> "a system of rewards and goals which motivate players, a narrative context which situates activity and establishes rules of engagement, learning content that is relevant to the narrative plot, and interactive cues that prompt learning and provide feedback" (Dondlinger, 2007, p. 22).

Inclusion of multi-modal characteristics in educational games requires a focus on learners' experience by integrating gaming elements into the learning process.

Educational games have become powerful learning tools, but they have disadvantages in terms of making connections among meaning, context and goals of learning. Gros et al. (2007) stated that motivation and engagement are two of the most important benefits of using educational games for learning. A recent meta-analysis discussed by Spires (2015) suggested that digital gameplay is more effective than other conventional methods of learning in terms of learning and retention in the major disciplines (e.g., biology, mathematics, language and engineering). However, there are some limitations in game-based learning. Gros et al. (2007) considered that educational games can produce a simplification of reality. The simplification of reality can break down the connections between conceptualizing the learning environment for learners and the meaning of game designs. Educational games are supposed to be user-centered by promoting challenges, co-operation, engagement, and the development of problem-solving strategies (Gros et al., 2007). It is a big challenge to design an authentic game-based learning environment in connection with reality.

Egenfeldt-Nielsen (2007) interpreted the relationship between educational games and learning theories by depicting the characteristics of a three-generation model. According to Egenfeldt-Nielsen et al. (2007), the first generation perspective, which outlines the existence of the *edutainment game*, corresponds with the dominating expression of edutainment. This generation assumes that learning occurs through the consistent practice of skill; therefore, quantity is regarded over quality of game play. The second generation, based on a cognitive aspect, is learner-centered. Critiquing the stimuli-and-response relation in behaviorism as being too simplistic, educational games present information and knowledge by catering to needs of specific learners. Learning design is customizable for individual learners according to their situations. Gros et al. (2007) maintained that people are not black boxes because they have previous knowledge, ideas and concepts, as well as different schemata and spatial ability. As problem-solving, analyzing and perceiving meta-skills are important in the twenty-first century, educational games facilitate learning with scaffolding clues and information. The third generation perspective constructing knowledge does not exclusively focus on a specific computer game, but looks at educational use of computer games in a broader process. In retrospect, the third generation does fit into learning in a specific context (e.g., meaningful learning and situated learning).

In the earlier research, Cobb (1994) contended that constructivist perspective and sociocultural perspective are complementary. Specifically, the constructivist trend is the view that students actively construct their learning by restoring coherence to the world of their personal experience, while the sociocultural trend emphasizes the socially and culturally situated nature of learning activities. The sociocultural perspective informs theories regarding the conditions that make learning possible, whereas theories developed from the constructivist perspective focus on what students learn and the processes by which they do so. Followed by constructivist and sociocultural trends, the three-generation model with various characteristics suggests that the evolution of games for educational purposes constantly adapts to the needs of the historically changing social practices.

While some learners benefit from learning in educational games, for others especially with little prior knowledge of this learning method the positive effect of game-based learning is reduced compared to other traditional methods of teaching and learning (Rondon, Sassi, & de Andrade, 2013). That is to say, educational games share many elements with other representational or signifying systems, including reading and writing. However, a lack of understanding of how educational games provide solutions (i.e., game characteristics) in relation to what the learners need from game (i.e., learning outcome) makes it difficult to use educational games to facilitate learning (Huang & Johnson, 2009). In response to this conflict, an integrated process for designing learning experiences is required to optimize the effect of educational games.

Wang and Chen (2012) stated that novice learners who are engaged in an interactive game-based learning environment might differ from more experienced learners in higher-order cognition and skills. They also explained game play as a cognitive tool, which is a technology-based scaffold in the learning environment, for enhancing knowledge construction. One explanation accounting for learning difficulties of those learners who are engaged in the game-based learning environment is the impact of cognitive overload (Horton, 2014). Woo (2014) indicated that digital game-based learning focuses on exploring content support for learning motivation and related game characteristics. On the contrary, isolation of specific learning tasks from the game characteristics might result in cognitive load and barriers to learning. Cognitive overload is a situation in which the processing demands may exceed the processing capacity of the cognitive system with regards to the performance of any learning task (Moreno & Mayer, 2007). For example, most people are unable to multitask because one task distracts them from another task they are trying to focus on in their processing cognitive system.

As far as instructional design is concerned, a focus on learning materials and instruction is implied. Consequently, methods and processes of instructional design are often reduced to the components of Analysis, Design, Development, Implementation and Evaluation (ADDIE), where one stage follows another in a linear sequence (Sims, 2012). However, designing game-based learning experiences entails *game design principles* (Folkins, Brackenbury, Krause, & Havilanda, 2016), *meaningful learning activities*

(Dyer, Hudon, Montpetit-Tourangeau, Charlin, Mamede, & Van Gog, 2015) and *clue-provided learning tasks* (Sykes, 2013), which move beyond instructional design. As an ideal substitute, LX Design is presenting practitioners with a broader blueprint about how to improve the learning experience of students using facilitators (e.g., tools, technologies and information).

Plaut (2014), a training coordinator for Apple and learning experience designer for General Assembly, believes that the process of designing human experience, regardless of purpose or platform, is centered around reaching a desired outcome by managing contributing factors in a specific experience. LX Design is a subset of User Experience Design (UX Design). An efficient way to examine a LX Design entails analyzing the essential components such as technologies (i.e., games), educational strategies (e.g., solutions to manage cognitive load), and content packages (e.g., curriculum designs). The theoretical basis for UX Design can be adopted to explain this process. Specifically speaking, LX Design is the application of UX Design in the field of education, thus the essence of UX design informs LX design. According to Herczeg (2006), LX Design inherits criteria of UX Design from aspects of *design* (e.g. aesthetic, experience and complexity) and *ergonomic* (e.g., controllability and conformity with user expectation). One of the typical representations is Garrett's Elements (Garrett, 2011). The model explains the conceptual framework about the components built from bottom to top. Namely, the five elements include Strategy, Scope, Structure, Skeleton and Surface (Garrett et al., 2011) from abstract to concrete. They are applied to delineate the learning experience from learners' needs to learning outcome by incorporating cognitive load and gaming features.

Existence of learning difficulties in a game-based learning environment—especially for K-12 can be attributed to the immature design of learning experience, as this report proposes. Cognitive Load Theory (CLT) accounts for the learning difficulties in game-based learning environments by describing how cognitive load impacts learning outcome. Kalyuga and Liu (2015) noted that cognitive load defines working memory resources required for completing a learning task or activity. Also, the magnitude of cognitive load is determined by the degree of element interactivity and the interconnectedness between the related elements of information that is processed simultaneously in working memory (Kalyuga et al., 2015). When students encounter a range of learning tasks, scarcity of prior knowledge and unfamiliarity with the game-based learning environment result in cognitive overload and learning difficulties. LX Design provides solutions to learning difficulties using premises from CLT.

Outline and Purpose of the Report

The purpose of this report is to conduct a literature review of articles from 2007 to present on several significant aspects dominating learning experience. Those aspects include educational games and cognitive load. This report presents findings and insights for researchers who are interested in how learning experience design provides solutions to learning difficulties in game-based learning in terms of cognitive load.

Moreover, separate terms (i.e., educational games and cognitive load) and their mutual relationship will be discussed to introduce learning experience design.

This report is divided into four chapters. Chapter 1 introduces the importance of LX Design and the role of cognitive load as an influential factor in game-based learning environments. It also discusses the outline and purpose of the report, and lists two guiding research questions. Chapter 2 discusses methodology of how this report is composed, and how the literature is chosen. Chapter 3 discusses findings in terms of the two research questions. The findings articulate how cognitive load impacts game-based learning and how LX Design provides solutions to learning difficulties related to cognitive load. Finally, this chapter applies Garrett's Elements (Garrett, 2011) to explain LX design. Chapter 4 concludes the findings and discusses the relationships between the findings obtained from the literature review and an empirical game-based learning environment, Alien Rescue Project. Alien Rescue, an immersive three-dimensional online learning environment, has been developed by the College of Education, University of Texas at Austin.

RESEARCH QUESTIONS

The research questions guiding this report of literature review are:

1. How does cognitive load impact game-based learning experience in K-12 education?
2. How does LX Design help address cognitive load issues in game-based learning environments?

Chapter 2: Method

This report reviews the literature from scholarly journals and books about cognitive load, educational games, game-based learning and LX Design. Although there are many articles about cognitive load, games and game-based learning, priority of the resources in this report concentrates on the empirical and theoretical journals from 2007 to present. As a new concept in the education industry, LX Design does not have many acknowledged theoretical resources to support itself since it has existed only for a limited period of time. Investigation into recent revolutions in the education industry and achievements in UX design provide insights into the design of game-based learning experience.

Several steps are employed during the research. First, the main theme and topic of the report are determined as the relationship among cognitive load, LX Design and game-based learning in the context of K-12 education. Then, the main theme and topic are split into individual keywords. The keywords play a vital role to make the search easier and to narrow the scope of the research. The initial search primarily focuses on the following online databases:

(1) Research Papers on Alien Rescue

(2) EdITLib

(3) ERIC (EBSCO)

(4) ERIC(Free)

(5) Google Scholar

(6) Wiley Online Library

(7) University of Texas at Austin Online Library

Different topics have various influences on specific times. The report thus centralizes on the findings based on articles published within the past decade.

After the initial search, numbers of results are shown as:

(1) 342 peer-reviewed online journals for a combination search of two keywords (cognitive load and game-based learning);

(2) 195 peer-reviewed online journals for a combination search of three keywords (game-based learning experience, cognitive load and learning difficulties).

Since focus of the search is on peer-reviewed journals from 2007 to present, the second search also applies inclusion and exclusion criteria to finalize the list of references, as follows:

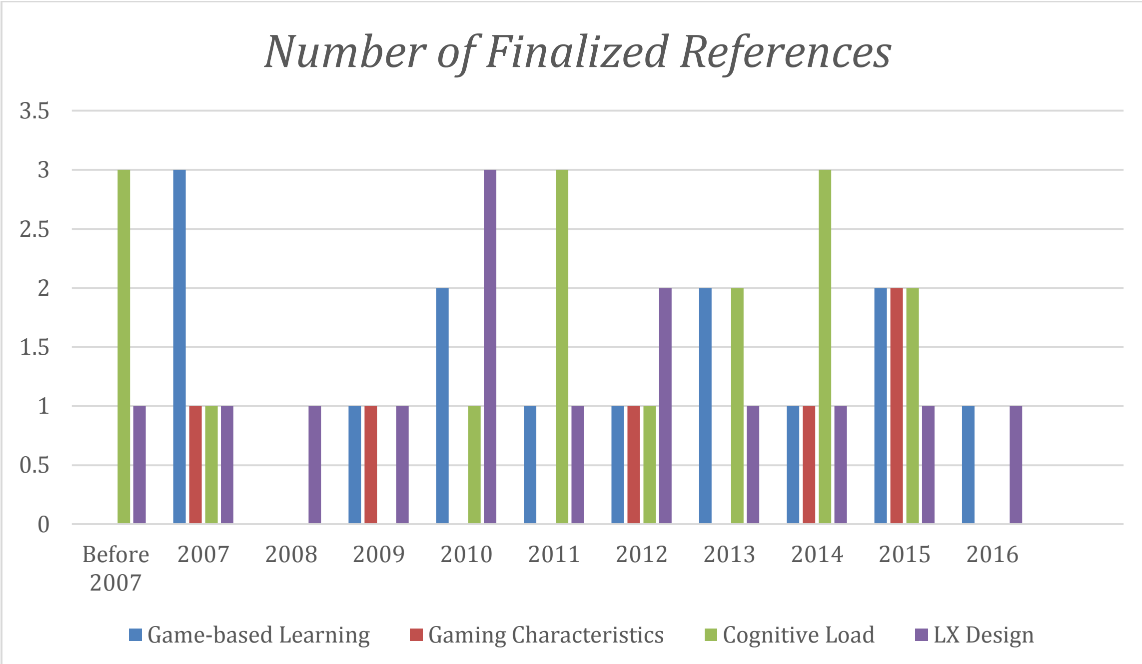
(1) focuses on three types of cognitive load in CLT under game-based learning environments

(2) relates gaming characteristics and features to cognitive load

(3) integrates the elements of solutions in UX Design into LX Design

The result of finalized references is shown in Figure 1.

Figure 1. Number of Finalized References



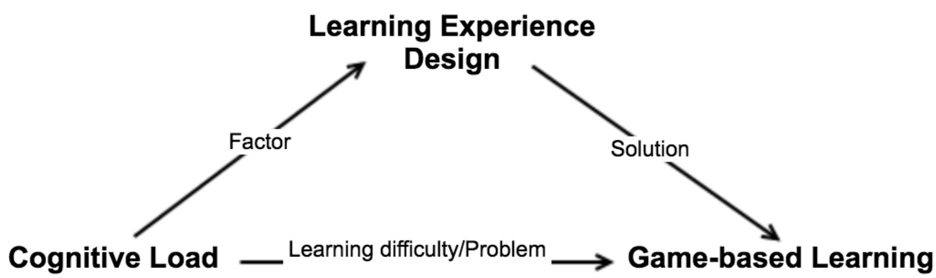
As shown in the bar chart, 52 articles are used as the references for this report. There are four categories of related topics, including game-based learning, gaming characteristics in educational games, cognitive load and LX Design. Eighteen articles that explain cognitive load using CLT and 14 articles that demonstrate the importance of LX Design, are reviewed to examine the casual relationship between cognitive load and LX Design as cause and effect. Seven articles that describe gaming characteristics and features are reviewed to investigate the affordances of educational games. After reviewing the significant gaming characteristics and features, 13 articles connect cognitive load and gaming characteristics, making it possible to interpret LX Design solutions.

Chapter 3: Findings and Discussion

This section addresses the two research questions by describing how cognitive load might result in learning difficulties and problems in game-based learning. After defining cognitive load as a factor of game-based learning experience, LX Design is used to provide solutions and strategies for game-based learning environments. Garrett's Elements (Garrett, 2011) is applied to explain LX Design using UX Design as enlightenment. The relationships among cognitive load, game-based learning and learning experience design are shown as Figure 2.

Cognitive load can either improve or hamper learning experience in traditional learning environments. Game-based learning environments, which have additional gaming elements (i.e., gaming functionality) and gaming characteristics, might cause cognitive overload without proper cognitive load managements. Cognitive overload can result in learning difficulties and other learning problems. In other words, cognitive load is a key factor that impacts learning experience. LX Design provides solutions for the problems that cognitive load causes in game-based learning environments. Specifically, LX Design primarily addresses extraneous cognitive load, but also germane cognitive load because intrinsic cognitive load is largely fixed for learners. The solutions by LX Design are explained by applying one UX Design model, Garrett's Elements (Garrett, 2011).

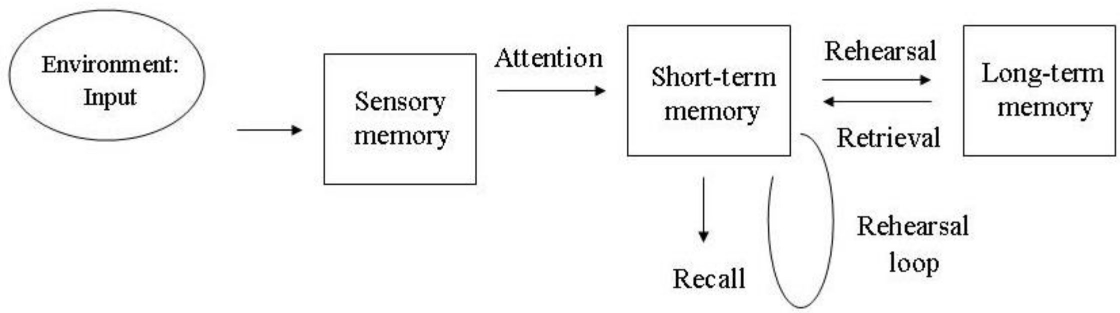
Figure 2. Relationship among Cognitive Load, Game-based Learning and LX Design



THE IMPACT OF COGNITIVE LOAD ON GAME-BASED LEARNING EXPERIENCE

As Huang et al. (2009) noted, connecting games' powerful characteristics and features with desired learning outcome is important to a systematic design of enhancing learning. Cognitive load is one of the most important factors to make connections between educational games and learning experience in game-based learning. Guttormsen Schär and Zimmermann (2007) stated that cognitive load is related to human information processing capacity. Specifically, human information processing capacity has limitations in terms of working memory. Miller (1956) put forward the magic number seven (plus or minus two) to describe the limited working memory between stimuli and responses. The magic number seven suggests that short-term memory can store between five and nine items and process information on simultaneously interacting elements with reliable accuracy and with validity. Atkinson and Shiffrin (1968) developed a multi-modal model of memory in terms of information processing, including sensory register, short-term store and long-term store as shown as Figure 3. Information is detected by the sense organs and enters the sensory register where it resides for a brief period of time. The short-term store is the subject's working memory; it receives selected inputs from the sensory register and also from long-term store. A control process called rehearsal can maintain a limited amount of information in short-term store. If rehearsal does not occur, then information is forgotten and lost from short term memory through the processes of displacement or decay. The long-term store is a permanent repository for information, which is transferred from the short-term store.

Figure 3. Multi-Modal Model of Memory



To discuss cognitive load, *CLT* (Sweller 1988; Sweller, 1994) outlines the complex tasks of optimizing learning by describing the relationship between limited *working memory* and unlimited *long-term memory* (Paas & Ayres, 2014), which constructs and automates mental schema. The schema of element interactivities is dependent on the complexity of learning materials and learner's expertise (Artino, 2008). As the conscious construction of information in working memory, our main processor of information is responsible for the acquisition of novel and unorganized knowledge. Repeated practice is required to create new schemas and automation in long-term memory. According to Kirschner, Kester and Corbalan (2011), learning occurs when chunks of new information are incorporated into existing schemas via assimilation or accommodation. Lower-level schemas are then assimilated into and continue to build upon complex higher-level schemas.

According to CLT, there are three types of cognitive load: intrinsic cognitive load, extraneous (or extrinsic) cognitive load and germane cognitive load. These three types of cognitive load can be divided into cognitive load that assists learning and that hampers learning (Zhang, 2013). Understanding the different types of cognitive load could provide solutions for overcoming working memory limitations through instructional manipulations and designs that are compatible with human cognitive architecture (Kirschner et al., 2011; Kalyuga et al., 2015).

(1) *Intrinsic cognitive load*, which is largely imposed by the number of interactive information elements in a given task, relates to difficulties of the subject matter (de Jong, 2010; Kirschner et al., 2011). Kibrick (2011) explained the intrinsic load as the portion of the learning goals or tasks that form the central purpose of learning materials. Specifically, learning materials that contain a large number of interactive elements are regarded as more difficult than learning materials that contain a smaller number of elements and/or have a low interactivity. de Jong et al. (2010) used vocabulary learning as an example of low interactivity materials while grammatical syntax serves as an example of high interactivity materials. Intrinsic cognitive load describes the relationship between the learner's previous knowledge, level of expertise and the complexity of learning materials (Zhang et al., 2013; Huang et al., 2015). Therefore, intrinsic cognitive load is inherent to tasks that vary by learning complexity.

(2) *Extraneous cognitive load* is caused by improper instructional design strategies and learning materials that do not directly contribute to schema construction in learning (de Jong et al., 2010). Kalyuga (2011) explained extraneous cognitive load as the cognitive activities used to understand the typical mechanics of the task design, rather than being geared toward the learning goals. Thus,

extraneous cognitive load does not assist in the learners' comprehension when they encounter complex learning tasks.

(3) *Germane cognitive load* is caused by information and activities that promote learning processes in terms of schema construction (Kirschner et al., 2011). Therefore, germane cognitive load is often associated with meaningful learning, and it constructs and strengthens organized knowledge structures or schemas in long-term memory (Kalyuga et al., 2011). It refers to learners' efficient cognition and motivation to the learning tasks and their cognitive resources that they can invest in the learning process (Zhang et al., 2013). Even though cognitive overload might result in learning difficulties by hampering learners' cognitive learning process, germane cognitive load supports learning in certain situations.

CLT serves as a significant theory when studying how cognitive load impacts learning. The limitation of working memory is a bottleneck for information processing, in general, and especially for learning. Cognitive overload happens once the information processing capability exceeds this limit (Huang, C. Chen, Wu, & W. Chen, 2015). After the central focus of CLT and three types of cognitive load have been discussed, this report will talk about cognitive load as a factor to react to gaming characteristics and attributes in game-based learning.

How Cognitive Load Relates to Characteristics and Attributes in Educational Games

Specific characteristics of relations in educational games are also seen as being related to learning difficulties (de Jong et al., 2010). Gaming characteristics and features are the key to examining challenges to cognitive load in educational games. An overview of the gaming characteristics that have been studied from 2007 to date is provided in Table 1.

Table 1. Summary of Gaming Characteristics and Attributes in Literature

Gaming Characteristics & Attributes	Description	Studies
Motivation/Reward System	Educational games have built in motivation or reward systems which are designed to reinforce learners' desired behaviors during game play. Motivation is related to the uneasy tasks and challenges learners are expected to complete.	Huang et al. (2009) Dondlinger et al. (2007) Groff, Howells, & Cranmer (2010) Folkins et al. (2016)
Challenge	Challenging activities in educational games provide a difficult enough but achievable level of difficulty for game play. Each challenge consists of clearly defined task goals, timely performance feedback and a sense of accomplishment.	Huang et al. (2009) Sauvé, Renaud, Kaufman, Duplaa, & Sénécal (2013)
Tasks	Tasks are several components which help build up the learning goal within the mission in educational games. Learners are often required to complete the tasks by following the sequences and the educational game is expected to provide timely feedback to learners' performance	Huang et al. (2009) Kirschner et al. (2011) Žavcer, Mayr, & Petta (2014) Lameras (2015)
Rules	Rules in educational games serve as guidelines and mechanisms for learners' actions. Rules are divided into knowledge-based rules and game-related rules. In the context of learning, game rules can be direct or indirect carriers of intended instructional materials related to knowledge (e.g., scientific concepts) that learners might have obtained. Game rules can be control principles of game play.	Huang et al. (2009) Lameras et al. (2015) Žavcer et al. (2014) Dondlinger et al. (2007)

Table 1 (continued)

Competition	Competition motivates learners to take risk-taking actions in a consequence-free environment. The competition can be implemented depending on the learning context (e.g., multiplayers).	Huang et al. (2009) Novak (2012) Sauvé et al. (2013)
Goals/Context/Cues	Goals in educational games state the final status of the learning progress. Sub-goals in educational games are often to present various stages of accomplishment for motivational and evaluation purposes.	Huang et al. (2009) Lameras et al. (2015) Dondlinger et al. (2007)
Fantasy & Reality	Fantasy in educational games creates unreal situations. Learners are motivated to follow the storyline in order to achieve the desired learning goals. The environments are often over-simplistic compared to reality.	Huang et al. (2009) Novak et al. (2012)
Role Playing	Role playing in educational games helps learners to identify as a character embedded in the storyline of the game. Role playing also establishes connection with learning and the fantasy world from the character's perspective.	Huang et al. (2009) Folkins et al. (2016)
Feedback	Feedback plays an instrumental role in encouraging knowledge construction through achievement of embedded learning goals and reflection on existing and completed learning activities.	Sauvé et al. (2013)
Usability (e.g., Control)	Usability is defined as the degree of learnability in the game. Control in educational games, specifically, enables learners to determine and predict the outcome of actions or events.	Huang et al. (2009) Saleh, Prakash, & Manton (2014)

Table 1 (continued)

Engagement & Curiosity	Presented with gaming elements (e.g., seamless task alignment, mystery and curiosity), learners consider involving themselves in the game is rewarding without extraneous motivators.	Huang et al. (2009)
Storyline & Representation	Storyline or representation motivates learners to interact, react and progress by connecting scenes in educational games. It is a summary of goals, rules, cues, role playing, contexts, and feedback for the learners.	Huang et al. (2009) Novak et al. (2012) Saleh et al. (2014)

As CLT suggests, manipulating cognitive load decreases the level of extraneous cognitive load and therefore increases germane cognitive load, which promotes deeper learning (Huang et al., 2009). This goal is also applicable to a game-based learning environment, which requires the game design to take cognitive load into full consideration. Game design built on the educational properties (i.e., cognitive load) can be an appropriate way to improve learning (Gros et al., 2007). Hence, elements in games (e.g., gaming characteristics) should be designed in terms of cognitive load management.

Managing cognitive load is an effective strategy to enhance learning experience in game-based learning. According to Kolfschoten, Lukosch, Verbraeck, Valentin and Vreede (2010), CLT defines intrinsic cognitive load as the cognitive load inherent to the task, specifically complexity of the intrinsic tasks. The authors also noted that extraneous cognitive load is caused by the presentation and transition method of information associated with cognitive processes that are not necessary for learning. Kalyuga et al. (2011) mentioned that germane cognitive load is intentional cognitive effort leading to learning and the corresponding learning-relevant demands on working memory. Different types of cognitive load reflect various perspectives about the relationship between learners' working memory and the desired cognitive processing. Thus, different strategies are adopted to manage the three types of cognitive load.

Managing intrinsic cognitive load in game-based learning environments is achieving interconnectedness between complexity of intrinsic tasks and the learners' expertise and previous knowledge in their long-term memory (Kalyuga et al., 2015). Individual difference is a key factor in managing intrinsic cognitive load. A study conducted by Rowe, Shores, Mott and Lester (2010) found striking differences between high- and low- achieving students in regards to problem-solving effectiveness, attention to particular gameplay elements, learning gains and engagement. Results showed that high-achieving students tend to demonstrate greater problem-solving efficiency, higher levels of interest and presence in game-based learning environments, and an increased focus on information processing gameplay activities. Lower-achieving students gravitate toward novel gameplay elements. Gros et al. (2007) indicated that the less advanced students benefit from educational games while the more advanced students connect meaningful learning with the game play. Expert reversal effect is one effective method to distinguish experts and novices in which cognitive load is reduced for novices and increased for experts (Kolfschoten et al., 2010). Expert reversal effect interprets how experts categorize their knowledge based on different solution modes to corresponding problems. In contrast, novices do not see the relationships between problems and solutions because they can only structure lower-level schemas based on the surface structures. For example, tasks in the same storyline are presented to all levels of learners while further challenges can be provided for advanced learners in the rewarding system of educational games. Part-whole approach is another way to manage intrinsic cognitive load by adjusting interactive information elements (Kirschner et al., 2011). Within part-whole approach, interactive information elements are initially reduced by simplifying the learning tasks, and as a result, more and more elements and interactions are added to accommodate the learners' previous knowledge and level of expertise. The availability of schemas determines the difference between experts and novices in certain circumstances (Sweller et al., 1988). One-size-fits-all game-based learning design is not applicable to both experts and novices. In other words, gaming elements (e.g., tasks and challenges) should be tailored to individual learner characteristics, technical, organizational, and other issues.

Extraneous cognitive load should always be reduced or even eliminated to remove unnecessary interventions, that exceed the limited capacity of working memory in a game-based learning environment (Kalyuga et al., 2011). Extraneous cognitive load is present only because game-based learning is designed in a way that requires learners to engage in cognitive processes and activities that are not necessarily required for acquisition of the intended goal (i.e., schemas) (Kalyuga et al., 2015). Related to game-based learning, some methods are suggested by CLT to be used in situations of extraneous cognitive load:

- Avoid splitting attention: Interactive elements of information are separated over storyline and locations that attention of learners might be distracted. Therefore, clues about mental integration of information elements should be provided to accommodate learners' search-and-match processes in game-based learning.
- Avoid redundancy: A common form of redundancy is presenting the same information in different modalities (Kalyuga et al., 2011). For example, presenting visual explanations using both text and audio produces redundancy compared to using images individually. Redundant components, such as irrelevant objects in 3D educational games, might decrease the speed in which learners interpret the game environment. Redundant components and modalities should be avoided in educational games to optimize the learners' cognitive activities.

Since unnecessary cognitive load (i.e., extraneous cognitive load) is reduced, memory space is left available for germane cognitive load, which is instrumental to building schemas. That is to say, germane cognitive load should be properly increased. Specifically, germane cognitive load can relate to motivation and engagement in designing game-based learning environments. To maintain concentration, learners should be able to allocate their working memory resources to the presented information elements. Specific methods and techniques that stretch beyond the boundaries of CLT are critical to facilitating learner motivation in game-based learning (Kalyuga et al., 2011). For example, game-based learning environments often involve high levels of learner controls. Learners might need to make their own decision about sequencing content of the tasks, pacing the presentation, and using the available clues and learning support based on the context of the game. Such cognitive processes could require additional working memory resources, thus potentially increasing levels of cognitive load (Kalyuga et al., 2015). If advanced learners with higher levels of prior knowledge could handle this load, it might result in learning difficulties for less experienced learners. Suitable techniques in educational games should be used to prevent this. A balance of managing intrinsic, extraneous and germane cognitive load thus come into action in game-based learning environments.

Many studies claim general balance among the three types of cognitive load depend on the total addition of them in the context of traditional learning. Kirschner et al. (2011) noted that the three loads are additive by increasing or decreasing each of them individually. However, Kalyuga et al. (2011) argued that the total cognitive load consists of intrinsic plus extraneous cognitive load rather than additive intrinsic, extraneous, and germane cognitive load under the traditional formulation. In other words, the total cognitive load determines the working memory required for processing all the involved elements of information and achieving learning goals within a specific task or tasks. However, the total cognitive load does not determine the allocated working memory of a specific learner in a specific learning situation. The amount of devoted working memory depends on how much the learner is engaged with game-based learning. Neither the total cognitive load nor the differentiated three types of cognitive load determine the distribution of the allocated working memory. If the total cognitive load exceeds the available and allocated working memory, the learner will fail in information processing involved in the learning tasks and will not achieve the learning goals. The challenge of matching appropriate level of cognitive load with the available working memory resources in learners' cognitive architecture requires a systematic framework of solutions.

SOLUTIONS TO COGNITIVE (OVER)LOAD BY LX DESIGN

While educational games offer many benefits for learning, they are not the solution to educational problems (Gros et al., 2007; Sykes et al., 2013). Game design or instructional design individually are insufficient strategies to addressing learning difficulties caused by cognitive overload in game-based learning environments. Game design concentrates on gaming elements, while instructional design emphasizes instruction and teaching rather than learning. Specifically, commercial game developers know little about training, education and instructional design while instructional designers know little about game design and development (Hirumi, Appelman, Rieber, & Van Eck, 2010). Another issue of instructional design is that little is understood about how to apply what we know about teaching and learning to optimize game-based learning. On the other hand, game design and development can not accommodate the goals of learning in games where fantasy and entertainment serve as priority. Such games (e.g., commercial games) might mislead learners to the product (i.e., game) itself rather than how learning occurs. Based on the limitation of isolating game design and instructional design, integration of the two design concepts can optimize game-based learning experience.

LX Design is the solution of applying instructional design theory to game design practice in game-based learning. The importance of experience is highlighted in some studies. According to Parrish, Wilson and Dunlap (2010), the object of experience is more holistic, requiring simultaneous attention to cognition, behavior, and affect when being compared to traditional behavioral objectives or discrete cognitive skills. Di Blas, Bucciero, Mainetti and Paolini (2012) noted that a game-based educational experience consists of several elements including content, syllabus, roles, sequence of activities, assignments and assessment procedures, which must be aligned with the affordances of the technologies used. Game design and instructional design have similarity and both result from a process that mixes the artistic, empirical, and analytic (Hirumi et al., 2010). LX Design is thus a package to facilitate learning by incorporating game design and instructional design elements in game-based learning environments.

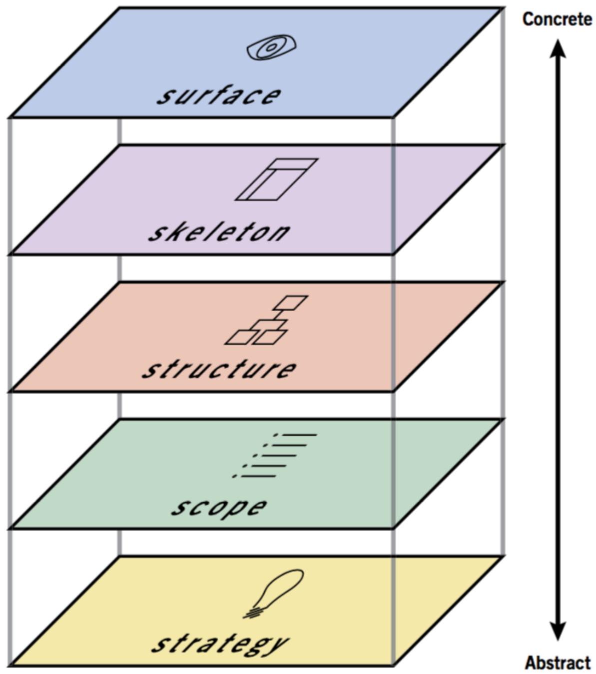
Learners' experience can not be discussed in general, even given the context of game-based learning. The fact is that the process of designing any human experience in different modalities, regardless of purpose, context or platform, is centered around the target user. UX Design represents the potential effort to engage users in specific situations and context to accommodate creating meaningful human experience. Even though different types of experience require their own unique methods and frameworks, the key elements should be taken into consideration during the design process. LX Design shares some important attributes with UX design, particularly with respect to processes. While LX Design borrows the thinking toolbox from UX design, one key aspect differs significantly—the move from the user-centered to the learner-centered. The basic idea of learner-centered design is that target learners of a system should play an important role in designing the system (Dong et al., 2015). However, LX Design might not be able to accomplish the determined goals in the specific learning context if it lacks meaningful models and paradigms that inform a scientific procedure.

Garrett's Elements

LX Design is the specific adaption of UX Design principles (Peters, 2013). Garrett's Elements (Garrett, 2011) is a systematic model or paradigm of UX Design to analyze the elements that are entailed in the process of any user experience. Five elements explain how decisions from different perspectives of the design are made to show how they influence the overall user experience. In this report, Garrett's Elements (Garrett, 2011) is applied to LX Design by providing its conceptual framework on solutions to the specific problems (e.g., impact of cognitive overload) in game-based learning environments.

The five layers of Garrett's Elements (Garrett, 2011) include Surface Plane, Skeleton Plane, Structure Plane, Scope Plane and Strategy Plane built from bottom to top, from abstract to concrete. Each of the five layers is dependent on the layer below it: the surface depends on the skeleton, which depends on the structure, which depends on the scope, and which finally depends on the strategy. With regards to game-based learning design, three dimensions are important, including a technological infrastructure, a conceptual framework for practice that focuses on the creation of structured sequences of learning activities, and a way to represent and share practice through the use of mediating artefacts (Masterman, Jameson, & Walker, 2009). At the top of the model, the major concern of game-based learning experience is the most concrete details of learners' behaviors and performances. However, at the bottom of the model, attention is drawn into how the overall learning experience fits into the strategy from a broader scope. General learning experience thus might be impaired if any layer is not rooted in the layer below it. The following sections discuss how Garrett's Elements (Garrett, 2011) helps LX Design provide solutions to problems (e.g., impact of cognitive load) in game-based learning.

Figure 4. Garrett's Elements Model



Solution 1 – Strategy (Bottom of Garrett's Elements)

The concerns of strategy come into play for both functionality-oriented products and content-oriented resources in game-based learning, as suggested in Garrett's Elements (Garrett, 2011). Rooted in functionality and content, game-based learning should have clear learning goals in terms of specific learning needs. Since the learner is the center in LX Design, two pairs of elements are the key factors of learner's goals and different learner needs, which are knowledge and skills, confidence and motivation.

As the impact of intrinsic cognitive load is suggested in CLT, complexity of learning tasks in educational games should be adjusted based on individual learner's previous knowledge and skills. For example, learners might lack enough information (e.g., scientific knowledge) or ability to apply such information to specific situations in the tasks of educational games. In "PISA 2012 Results: Ready to Learn: Students' Engagement, Drive and Self-Beliefs", students are motivated to learn by selecting appropriate learning goals to guide the learning process, using appropriate knowledge and skills to direct learning and selecting learning strategies appropriate to the task at hand. On the other hand, germane cognitive load suggests meaningful learning by motivating learners to complete tasks in educational games and by building learners' confidence when setting the complexity of tasks. That is to say, the initial solution in LX Design to cognitive (over)load is to determine the overall learning goals and learning needs by adapting the complexity of tasks to learners' individual differences for educational games.

Solution 2 – Requirement (Scope)

After identifying the overall learning goals and learning needs, Garrett's Elements (Garrett, 2011) suggests the importance of deciding the scope of game-based learning requirements in terms of functionality and information. In the original prototype of Garrett's Elements (Garrett, 2011), the layer of scope further extends the layer of strategy by identifying functional specifications and the form of content requirements. Functional specifications in Garrett's Elements (Garrett, 2011) are considered as detailed descriptions of the feature set of the products (i.e., educational games). Content requirements, on the other hand, are a summary of various content elements in LX

Design. Artino et al. (2008) indicated that pieces of irrelevant components should be eliminated in learning process, otherwise they might result in cognitive overload (e.g., extraneous cognitive load) due to the unnecessary working memory. Parrish, Wilson and Dunlap et al. (2010) also thought that such cognitive overload might have a negative impact on quality of game-based learning experience. Based on the learning goals and learning needs in game-based learning, a clear definition of the requirements should include the necessary content in LX Design in terms of learners' previous knowledge, just as instructional design does. Also, the requirements of functionality in LX Design should define the most important elements in game design rather than creating all the pieces for entertainment and fantasy.

Solution 3 – Structure

Packaging functionality and content (basic game-based learning components) requires a structure to facilitate learning experience. The functionality requirements are embodied by interaction design, in which functionality is defined as how the learning system behaves in response to the learner. On the side of content, structure is the information architecture or the arrangement of content elements to facilitate cognitive learning. A learning experience is considered as a success when it is designed and structured in the way that makes the learning process in a logical cycle. As intrinsic cognitive load in CLT suggests, that sequence of multiple learning activities (i.e., tasks) might impact learners' comprehension of potential knowledge in educational games. Specifically, one task might be built upon the other tasks. If there is no clue or context to connect different tasks, learners (especially novices) might encounter learning difficulties and cognitive overload. Content elements—including topics, activities, logistics, and assessments—should be structured by functionality (i.e., game characteristics) which applies game rules to regulate the track of learners' behaviors in the storyline of game-based learning environments.

Solution 4 – Interaction (Skeleton)

On the layer of interaction, the structure of game-based learning experience is defined by how learners actually experience the content through the affordances of interface and information design. Interaction design, which is the generalization of interface and information design, takes learners' attention and extraneous cognitive load into consideration (Peters et al., 2013). As the research by Peters et al. (2013) showed, the more brain activity (i.e., attention) the user allocates to interaction, the less is available for learning. As a result, unnecessary interaction might present extraneous cognitive load in educational games.

Shi and Shih (2015) noted that all interactions and conflicts occurring between the game and the learners are included in the interaction factors, such as user interface. The interaction factors make the intangible learning structure concrete. Specifically, interaction design involves determining consistent buttons, fields, navigation and other interface components in order to display the game elements in a holistic way.

Information design, on the other hand, clearly displays learners' information for effective communication in educational games. Learners' information includes their progress of learning and their personal profile, which can be tracked in the game. For example, the progress of learning can be quantified as the number of learning tasks that have been completed. Integrating information design, learners can be aware of their learning progress and self-regulate the strategies based on the clues and context in educational games. Assessments, defined within the layer of requirements, should be used in LX Design to evaluate a learner's skill-level or knowledge-level, and how the learning progress is communicated back to learners

Solution 5 – Sensory (Top of Garrett's Elements)

On the sensory layer of the model, the overall learning experience (i.e., general look and feel) matters in catering to the sense of the learner. Sensory elements allow learning materials to implicitly communicate information to the learner about their learning experience. In terms of game-based learning environments, sensory elements provide various modalities to shape the dynamic learning infrastructure. The shift from two-dimensional (e.g., images, 2D animation) to three dimensional (e.g., virtual reality, simulation, videos and 3D animation) game-based learning environments illustrates the significance of technology in delivering learning materials. Redundancy in providing various representation modalities (e.g., text, audio, video, animation and etc.), which are far from necessary in educational games, might cause extraneous cognitive load. This accounts for why instructional design will be less effective when designing learning materials remains its priority and focus. As a substitute, LX Design is critical in the professional education industry, as the synthesis of instructional design, educational pedagogy, neuroscience, social sciences, design thinking, and UI/UX Design. LX Design provides the solution in which learners' satisfaction is influenced by overall learning experience in educational games.

Cognitive load comes into play throughout Garrett's Elements (Garrett, 2011). There is no one-size-fits-all strategy for all kinds of learning experience design. The five layers are intuitive when different combinations of factors (i.e., content of learning and functionality of the game) are embedded in in the learning process. Different learning scenarios require both necessary cognitive load and effective strategies to eliminate the unnecessary cognitive load that might hamper learning. When students are engaged in learning tasks, they are constructing the knowledge and skills through meaningful learning. LX Design, which provides solutions to learning difficulties and issues caused by cognitive overload, creates meaningful learning in game-based learning environments.

Chapter 4: Conclusion and Implications

This report primarily reviews the literature from 2007 to present on the relationship among cognitive (over)load, game-based learning and LX Design. Although there are many parameters influencing the research results, LX Design is demonstrated to be an effective education strategy and procedure in game-based learning, impacted by cognitive load.

In terms of the first research question, this report concludes that there are different ways to label cognitive load: unnecessary and necessary cognitive load, or intrinsic, extraneous and germane cognitive load in CLT. The impact of cognitive load is discussed by connecting to 12 gaming characteristics and features, which include motivation/reward system, challenge, tasks, rules, competition, goals/context/cues, fantasy/reality, role-playing, feedback, user control, engagement and curiosity, and storyline and representation. Under this circumstance, there are several factors which contribute to impact cognitive load throughout game-based learning experience:

a) the relationship between learners' level of expertise and previous knowledge and the complexity of the learning tasks in educational games (suggested by intrinsic cognitive load)

b) the individual differences between advanced and novice learners (suggested by intrinsic cognitive load)

c) the balance among unnecessary cognitive load (i.e., extraneous cognitive load), necessary cognitive load (i.e., germane cognitive load) and cognitive that should be managed depending on the situations (suggested by total cognitive load).

Regarding the second research question, Garett's Elements is found to be a systematic framework for analyzing the elements entailed during the process of any user experience. LX Design is a domain-specific user experience that shares the similar characteristics with UX design; therefore, Garett's Elements can also be applied to LX Design. From the bottom to the top, content and functionality of the learning process flow in the five layers of Garrett's Elements (Garrett, 2011)—strategy, requirement, structure, interaction and sensory. Strategy can be explained as learner's needs and the objectives and goals of the learning process. Requirement relates to functional and content requirements. On the layer of structure, interaction design and information architecture play a significant role. In that sense, appropriate arrangement of any learning-related information (e.g., curriculum and materials) should be designed to be compatible with learning activities in which learners are supposed to involved. Interaction is divided into information design and interface design in which learners can use the well-organized learning materials to engage themselves in learning activities, in order to construct meaningful learning. Sensory, mostly emphasized by instructional design, should provide an appropriate number of modalities in game-based learning environment. For example, in game-based learning environments, whether the educational game is three-dimension or two dimension should also be taken careful consideration.

The findings of this report will be applied to Alien Rescue project (i.e., a three-dimension online learning environment) of which I am one of the members. The implications for Alien Rescue include as followed:

(1) Overall, the researchers in Alien Rescue project are creating every effective educational strategy as a solution to solve the problem of the students. The pitfall is that the researchers are designing for a better tuned learning experience, instead of creating and directly designing learning experience.

(2) In terms of different factors of cognitive load in game-based learning, it is important for the researchers to think about whether designing the 3D learning environment is worth putting in effort as compared to the 2D learning environment. Fantasy and mystery could not explain the reason why 3D learning environment is better than 2D learning environment. We all know the tricky pitfall is that an instructional designer will consider the surface level of learning (e.g modality of learning) as the most straightforward but easy-to-understand packaging of learning design.

(3) It's important that efficient educational game development should "collaborate" with instructional design for a good learning experience. If game developers are disconnected with learning materials, they will have difficulty making decisions on the game design; It is difficult for curriculum designers to evaluate the value of the game elements if the curriculum designers do not familiarize themselves with the technology environment. In that sense, getting everyone who wears different hats to collaborate with each

other and to work on the documentation flow are useful strategies during the project running.

d) Affordances of different cognitive load should be taken careful consideration in Alien Rescue before researchers decide to fill in the learning space with additional elements.

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