THE EFFECTS OF SINGLE LOOP AND DOUBLE LOOP LEARNING WITH PEER SCAFFOLDING IN PROBLEM-BASED GAMING ON SCIENCE PROCESS SKILLS AMONG FIFTH GRADE STUDENTS

by

RAHELEH RAHMANI

Thesis submitted in fulfillment of the requirements

for the degree of

Master of Arts

February 2013

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LIST OF ABBREVIATIONS

PBG	Problem-Based Gaming
SLL	Single-Loop Learning
DLL	Double-Loop Learning
ZPD	Zone of Proximal Development
GOM	Game Object Model
PBL	Problem-Based Learning

KESAN GELUNG PEMBELAJARAN TUNGGAL DAN BERGANDA BERSAMA PERANCAHAN DI DALAM PERMAINAN BERASASKAN MASALAH TERHADAP KEMAHIRAN PROSES SAINS DALAM KALANGAN PELAJAR TAHUN LIMA

ABSTRAK

Tujuan kajian ini ialah mengkaji mekanisme-mekanisme penglibatan pelajar di dalam permainan berasaskan masalah bersama perancahan dan kesannya terhadap kemahiran-kemahiran proses sains asas dan bersepadu. Di dalam permainan berasaskan masalah pelajar akan menempuhi langkah-langkah penyelesaian menggunakan gelung pembelajaran tunggal dan berganda merentasi pelbagai aras permainan tersebut. Satu kajian kuasi-eksperimen melibatkan dua buah kelas sedia ada telah jalankan. Sampel terdiri daipada 72 pelajar tahun lima lelaki dan perempuan. Sebuah kelas telah tugaskan untuk bermain secara individu manakala sebuah lagi bermain secara berpasangan bersama rakan pilihan mereka sendiri. Semakan skor pencapaian pelajar di dalam sains menunjukkan perbezaan yang signifikan di antara kelas-kelas ini, maka skor pencapaian pelajar di dalam sains telah digunakan sebagai kovariat. Pembolehubah bebas kajian ialah perancahan rakan sebaya manakala pembolehubah bersandar ialah tahap refleksi, tahap penglibatan dalam gelung pembelajaran tunggal dan berganda, dan prestasi dalam kemahiran proses sains asas dan bersepadu. Instrumen yang digunakan ialah Ujian Pencapaian Sains Tahun Lima Ohio (2007) untuk mengukur prestasi pelajar dalam kemahiran proses sains asas dan bersepadu, borang catatan mata kemenangan untuk setiap aras permainan untuk mengesan tahap penglibatan semasa bermain, dan satu soalselidik refleksi. Data ini kemudian digunakan untuk menganalisis prestasi kemahiran proses sains asas dan bersepadu mengikut tahap penglibatan pada gelung pembelajaran tunggal dan bersepadu.

Dapatan menunjukkan bahawa pelajar dalam kumpulan perancahan rakan sebaya melaporkan min yang lebih tinggi dan berbeza secara signifikan pada refleksi dan penglibatan dalam gelung berganda berbanding pelajar dari kumpulan individu. Walau bagaimanapun, tidak terdapat perbezaan yang signifikan di dalam prestasi kemahiran proses sains asas dan bersepadu. Analisis seterusnya mendapati bahawa di dalam kumpulan perancahan rakan sebaya yang bermain pada gelung pembelajaran berganda melaporkan min yang lebih tinggi dan berbeza secara signifikan untuk kemahiran proses sains asas dan bersepadu berbanding pelajar yang bermain pada gelung tunggal, manakala tidak terdapat perbezaan yang signifikan pada prestasi kemahiran proses sains asas dan bersepadu dalam kalangan pelajar kumpulan individu yang bermain pada gelung tunggal dan bersepadu. Juga, tidak terdapat kesan interaksi antara kaedah bermain dan paras penglibatan bermain pada gelung pembelajaran tunggal dan berganda untuk prestasi di dalam kemahiran proses sains asas dan bersepadu. Dapatan kajian ini mencadangkan bahawa permainan berasaskan masalah bersama perancahan rakan sebaya sesuai digunakan untuk membangunkan kemahiran proses sains.

THE EFFECTS OF SINGLE LOOP AND DOUBLE LOOP LEARNING WITH PEER SCAFFOLDING IN PROBLEM-BASED GAMING ON SCIENCE PROCESS SKILLS AMONG FIFTH GRADE STUDENTS

ABSTRACT

The purpose of this study is to investigate the mechanisms of engagement in problem-based gaming with scaffolding and their effects on basic and integrated science process skills. Problem-based gaming (PBG) postulates that players engage in single-loop learning (SLL) and double-loop learning (DLL) when they solve problems through the various levels of a game. A quasi-experimental study involving two intact classes was employed with a sample comprising 72 male and female fifth-grade pupils. One class was assigned to play the game individually and the other in pairs, with the pupils choosing their own partners. An evaluation of the students' achievement in science indicated significant differences between the two classes. Therefore, the students' science achievement scores were used as a covariate. The independent variable was peer scaffolding, and the dependent variables were the learner's intensity of reflection, levels of engagement in the game in the form of single-loop learning and double-loop learning, and performance in basic and integrated science process skills. The instruments consisted of the Ohio achievement assessments of science (2007) for grade 5 to evaluate the performance of students in basic and integrated process skills, a game-playing log to record reward points for each level and evaluate the level of engagement during the game, and a reflection questionnaire. Further analysis was conducted to investigate the performance in basic and integrated science process skills by the level of engagement in single-loop learning and double-loop learning.

The findings show that students in the peer-scaffolding group reported a significantly higher mean for reflection and engagement in double-loop learning than did the students in the individual group. However, there were no significant differences in basic and integrated process skills between the peer scaffolding and the individual groups. Further analyses showed that, for the peer scaffolding group, the double-loop learning users reported a significantly higher means for basic and integrated science process skills than did the single-loop learning users. For the individual group, there were no significant differences in basic and integrated process skills between the double-loop learning and the single-loop learning users. There were also no significant interaction effects between the treatment methods and the level of engagement in the game for basic and integrated science process skills. This information is useful in developing scientific thinking by employing modified problem-based gaming with peer scaffolding.

CHAPTER 1

INTRODUCTION

1.1 Introduction

Programs that teach students to think like scientists are effective (Handelsman, Miller and Pfund, 2007). Through such programs, students learn to solve problems in multiple contexts and integrate information into meaningful and reasonable scientific concepts. In the 21st century, education necessitates the training of creative, critical, and independent thinkers, with the development of cognitive skills as the main goal. Thus, science process skills were included in the curriculum to develop the problem-solving skills of students (Leongson & Limjap, 2003; Lan et al., 2007; Martin et al., 2004; Mei et al., 2007; Miles, 2010). Padilla (1990) defines science process skills as "a set of broadly transferable abilities, appropriate to many science disciplines and reflective of the behavior of scientists." TIMSS (the Trends in International Mathematics and Science Study) (2011) translates these behaviors into cognitive processes involving knowing, applying and reasoning and apply them across grades four and eight in assessing performance in science and engagement in scientific inquiry. Science process skills are defined at two levels: basic and integrated. The basic science process skills are observation, communication, classification, measuring with numbers, inference, prediction, and using the space-and-time relationship. These simple skills establish a foundation for more complex integrated skills. The integrated process skills are interpreting data, controlling variables, defining operationally, formulating hypotheses, and experimenting (Padilla, 1990). Both basic and integrated process skills have been considered in existing science education standards and reforms (Miles, 2010).

The teaching of these skills is founded on the interpretation of the Piagetian theory in connection with the need for child-centered "active learning" (Adey & Harlen, 1986). In the studies of Piaget on the cognitive activities of children, concepts are organized as schemes in the mind; these schemes are modified from experience through the processes of assimilation and accommodation. Assimilation is when an event or object is dealt with in a manner that fits into an existing scheme. Accommodation occurs when the existing scheme has to be modified or recreated to account for the new object or event (Pritchard & Woollard, 2010). In this regard, basic process skills are connected to assimilation, and integrated process skills are related to accommodation in which the existing scheme must be reconstructed (King, 2011).

A central aspect of Piaget's theory is that children develop their thinking through stages, namely, the sensorimotor stage (from 0 to 2 years old), the pre-operational age (from 2 to 7 years old), the concrete operations stage (from 7 to 11 years old), and the formal operational stage (after 11 years old) (Valanides, 1998). Each stage represents children's way of thinking and understanding the world (Wood et al., 1987). In concrete operations, children can apply mental operations on certain objects, and in the formal operational stage, children can expand the ability to handle abstract concepts or ideas (Leongson & Limjap, 2003). Thus, according to the Piagetian stages of cognitive development, basic process skills can be fostered in the early stages of cognitive development, and integrated skills can be introduced in the formal operational development at approximately 11 years old (King, 2011). So, the critical age to teach integrated process skills is around 11 years old, when the ability for higher-order thinking has emerged.

A considerable gap exists between knowledge acquisition of students and higher-order thinking skills and cognitive skills in students' learning (Gonzales et al., 2009; TIMSS, 2007; PISA, 2009). In Malaysia, these skills are incorporated into both the primary and secondary school curricula (Lan et al., 2007), and students are exposed to various aspects of science and inquiry-based learning in the classroom and the science laboratories. However, the evaluation of students on science competencies in national and international surveys, such as the Program for International Student Assessment (PISA) and the Trends in International Mathematics and Science Study (TIMSS), in Malaysia consistently indicates low performance in tasks that require science process skills, especially integrated skills. For example, the TIMSS 2003 International Science Report established international benchmarks for science achievement from the data of 46 countries, including Malaysia, for the eighth grade. The performance of students at lower benchmarks is characterized by elementary knowledge of basic science facts, whereas at the advanced benchmarks, the students can draw on more abstract conceptual knowledge and engage in integrated science process skills. For Malaysia, on average, the percentages of students that reached each benchmark are reported at 4% for the advanced benchmark, 30% for the high benchmark, 71% for the intermediate benchmark, and 95% for the low benchmark. Moreover, the science achievement of students is reported to be lower than the international average (Martin et al., 2004). These findings indicate the need to improve the teaching and learning of science process skills.

Lawson (1995) proposes the use of the teacher-led inquiry-based learning cycle method to teach scientific thinking. Students begin by exploring a new phenomenon to create disequilibria in their schema, and while the students are in a cognitively conflicted state, the teacher offers tentative answers or procedures that students improve on by generating and testing alternative solutions or new arguments to reestablish equilibrium. Collins and Stevens (1983) offer a set of teacher-led inquiry-based learning strategies to force students into deep thinking and continuous review of their knowledge and beliefs when learning science. These models and many others like them are founded on the belief that scientific thinking skills are better taught by an expert and in a formal setting instead of acquired independently at home. Padilla (1990) clarifies that science process skills cannot be developed by students unless through inquiry in different contexts and content areas. However, all aspects of inquiry — from posing a question to designing an investigation and experimenting — are difficult for students and schools to conduct because of practical and logistical constraints such as the lack of laboratory facilities and supplies to adopt inquiry approaches (Honey & Hilton, 2011). Thus, developing science process skills is a multifaceted problem**.**

1.2 Background of the Problem

1.2.1 Video Games and Learning

Computer games provide an opportunity for students to overcome curricular and logistical obstacles to achieve inquiry-based learning (Honey & Hilton, 2011). Complex inquiry-based computer games provide a new method to acquire knowledge and skills in a constructivist manner in which players can examine their hypotheses and strategies as well as receive feedback (Jong et al., 2010). A number of studies have shown that computer games enhance children's cognitive development (Buchanan, 2003; Plowman, 2005) and in particular improve their higher-order cognitive processes (Pillay, 2003; Ko, 2002). Thus, the US Committee on Science Learning of the National Research Council (2011) acknowledged digital games as a worthy resource that deserves future investment and investigation to improve science process skills (Honey & Hilton, 2011). In this study, the terms “video game,” “computer game,” and “digital game” are used interchangeably.

Egenfeldt (2006) classified video games that are used in education in three categories. The first category includes commercial educational video games or edutainment videos, which focus on directly teaching specific skills such as spelling or algebra. These games are strong in education but weak in motivation or entertainment. The games of Math Blaster, Pajama Sam and Castle of Dr. Brain are in this category. The second category includes research-based educational video games that are developed through educational research for learning. However, their production is extremely expensive. Phoenix Quest, Oregon Trail, Logical Journey of the Zoombinis, and Global Conflicts: Palestine are examples of the games belong to this category. The third category includes commercial games that seldom focus on scientific issues and that are unsystematically used for education. They have indirect focus on the learning process. Games in this category include SimCity and Civilization which are used by several schools. Each game, regardless of the category, is related to a genre. In general, there are eight distinct genres: adventure, platform, puzzles, role play, shooters, sports, strategy, and casual, which have different benefits and drawbacks in terms of their applicability for learning in education (Whitton, 2009). The games under discussion in this study belong to the third category. Gee (2003) advocates employing commercial games for education, stating that "many bestselling recreational games are already state-of-the-art learning games as they are hard but fun, time-consuming but enjoyable, and complex but learnable."

1.2.2 Theoretical Support for Learning from Games

Scientific thinking skills can be improved by playing video games that involve trying to find an answer or solving a problem (Anderson, 2009). Several studies on game-based learning confirm the positive effect of learning through games (Adam, 1998; Gee, 2003 and 2005; Squire 2005; Aylett, 2005; Johnson, 2005; Shaffer, 2006; Ip et al. 2007; Jong et al., 2007; Cameron, 2008). To incorporate learning elements into video games and to have a motivating medium to engage players in the process of learning, the structure of digital games must be reconsidered. Moreover, the external factors that can affect the level of immersion in the game must be taken into account. In this study, two approaches to learning are considered as the foundation of the study: the problem-based gaming (PBG) model proposed by Kiili (2007) and peer scaffolding.

1.2.2.1 Problem-based Gaming (PBG) Model

Kiili (2007) proposes the PBG model to illustrate the learning mechanisms involved in playing inquiry-based games. Based on the model, the interaction of the game elements can be explained better. In PBG, learning occurs in the game world as a cyclical process of direct experience. The model suggests that the games can be played at the surface level through single-loop learning (SLL) or at the deeper levels of exploration and engagement through double-loop learning (DLL), with an important conjunction of reflection (Kiili, 2007). Details about the model and its background are explained in Chapter 2.

1.2.2.2 Peer Scaffolding

Vygotsky (1989) introduced the term “scaffolding” to mean learning assistance. In the socio-cultural approach to cognitive development suggested by Vygotsky, interacting with others results in the construction of knowledge for learners (Shen & O’Neil, 2008). Vygotsky (1989) also introduced the “zone of proximal development” (ZPD), which refers to the area between what the learner can do alone and what the learner can do with assistance. Vygotsky declares that the learner can master the task in the ZPD if he/she receives proper support or assistance. The term “peer scaffolding” refers to situations in which a peer assists the learner to complete a task or solve a problem that the learner is unable to accomplish alone (Gray & Feldman, 2004). Shen and O’Neil (2008) assert that peer scaffolding supports learning and problem solving.

1.2.2.3 PBG Model, Peer Scaffolding and Development of Science Process Skills

Computer games provide a great opportunity to promote inquiry-based learning (Honey & Hilton, 2011). A number of studies show that computer games can enhance children’s cognitive development (Amory et al., 1999; Beavis, 2002; Buchanan, 2003; Plowman & Stephen, 2005), particularly their higher-order cognitive processes (Betz, 1996; Pillay, 2003; Ko, 2002). However, a significant gap still exists in understanding the processes of interaction with the game elements to improve learning and science process skills. The interaction of the game elements can be explained better by using the PBG model developed by Killi (2007) to illustrate the learning mechanism in games.

In this study, the PBG model is modified to reintegrate the pedagogical elements suggested by Piaget (i.e., assimilation, accommodation, and schema construction) and Vygotsky (i.e., peer scaffolding) to explain and illustrate the mechanisms of cognitive engagement in playing complex games. Such games offer several levels of activities or problems to be completed, each with increasing difficulty, before the game is won. The completion of the basic or familiar tasks at each level requires only SLL, whereas the completion of the advanced or more complex tasks requires DLL. The concepts of SLL and DLL were originally defined by Argyris and Schön (1974) and further elaborated for use in games by Kiili (2007). In game playing at the SLL level, the player only fosters the previous schemata and develops the process of assimilation, whereas at the DLL level, the player constructs a new schema by developing a new strategy to improve the process of accommodation.

In the modified PBG model, playing usually starts with exploring a challenge. The player identifies the challenges that the game provides and forms an early set of playing strategies through a simple active experiment to meet the challenge. Based on the results of the initial strategies, the player performs an assessment or reflection and modifies his/her schema through assimilation. In this way, the player can use the science process skills that he/she already possesses to conquer the obstacles or challenges in the game and to form an early schema for knowledge about the game. The feedback and reflection processes determine the modification of the schemata and consequently the player's behavior. The reflection stage enables the player to decide whether to continue the earlier scheme at the SLL level or to construct a new scheme through accommodation by changing the strategies and moving into the DLL level (Kiili, 2007). In other words, based on cognitive development, in SLL, only assimilation occurs, and the player works in the concrete operational stage, which does not require higher-order thinking skills. By contrast, in DLL, the player works in the accommodation domain. The player functions in the formal operational cognitive stage and can use higher-order thinking skills or complex science process skills in the context of the game. The modified version of the model is illustrated in Figure 1.1.

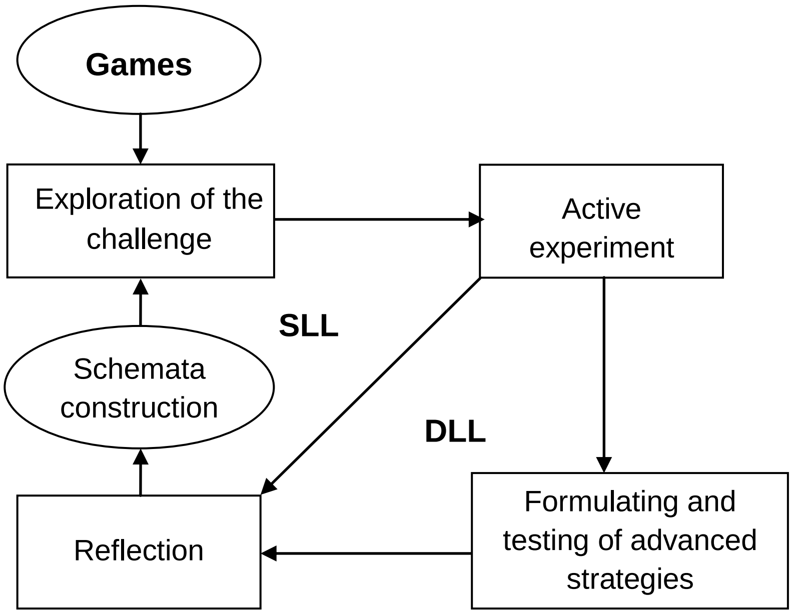

Figure 1.1: Modified PBG model (from Kiili, 2007)

However, the DLL processes in a game can be extremely challenging and time consuming to the point that a large number of players do not complete certain levels and eventually abandon the games. Thus, engaging in DLL requires additional external inputs such as peer scaffolding. In studies involving instructional settings, peer scaffolding has been shown to be a catalyst in deep processing (Wertsch et al., 1991; Jeris, 1997). In the PBG model, Kiili (2005) anticipates that reflection will mostly occur in groups or pairs. Playing with a peer can foster the process of reflection for the players. In this way, while solving the problem in pairs or groups, the final reflection and schemata construction also occurs separately for each player. Thus, it appears that peer scaffolding has the potential to facilitate DLL. Kiili's modified model explains the mental behavior of students while actively engaged in the game. It is silent in secondary mental behaviors that are triggered through post-activity reflection or incubation (Wallas, 1926), which has been shown to contribute to successful problem solving. According to Wallas (1926), when conscious attention is diverted from the problem, the problem is internalized into the unconscious mind and incubation occurs. Thus, these mental activities are triggered through prolonged engagement in any problem-solving task.

1.3 Problem Statement

Although there are numerous studies on the field of enhancing children's cognitive development through computer games (Amory et al., 1999; Beavis, 2002; Betz, 1996; Pillay, 2003; Buchanan, 2003, Ko, 2003; Plowman & Stephen, 2005), there is still a significant gap in understanding the processes of interaction with the game elements to improve science process skills. The interaction of the game elements can be explained better by using the modified PBG model that employs SLL and DLL to describe the player's level of engagement in complex games. The SLL and DLL paths are affected by the difficulty of the tasks. The modified PBG model consisting of both SLL and DLL paths has the potential to explain the processes of improving science process skills involving complex inquiry-based games. For new and difficult tasks, learners start with SLL and proceed to DLL upon achieving sufficient mastery. Given that entering into DLL requires additional proficiencies, players may refuse to engage in DLL and decide to remain in SLL or give up the game.

Engaging in DLL can be enhanced by additional external inputs such as peer scaffolding. In studies involving instructional settings, peer scaffolding has been shown to be a catalyst for driving deep processing (Wertsch et al., 1991; Jeris, 1997). However, no study has investigated whether students engaged in PBG with scaffolding in games of various levels of difficulty are more likely to engage in DLL and subsequently enhance their basic and integrated process skills better than students in PBG without scaffolding. Thus, following Wertsch et al. (1991) and Jeris (1997), students in PBG with peer scaffolding are hypothesized to perform more DLL cycles as they advance through the various levels of the game. Consequently, they improve their performance in science process skills; whereas students in PBG without scaffolding perform more SLL and score lower in both basic and integrated science process skills. Following the work of Rebetez et al. (2005), Schrier (2007), Kiili (2007), and Payne (2010), students in the peer scaffolding group are hypothesized to report better reflection than those in the individual group and that the DLL users in both peer scaffolding and individual groups perform better in both levels of science process skills than their peers in the individual group.

1.4 Purpose of the Study

A number of studies reveal the positive effects of playing certain video games in promoting scientific thinking skills, but few of them discuss the process of developing this kind of skills through video games (Anderson et al., 2009). In the constructivist perspective, the major challenge is to engage the player in discussing the game and reflecting on it for constructing knowledge rather than simply transferring certain concepts (Egenfeldt, 2006). In this manner, learning is a cognitive and socio-cultural interaction in an engaging environment (Otting & Zwaal, 2007). The purpose of this study is to investigate the mechanisms of engagement in complex games that enhance constructivist learning from the cognitive and socio-cultural perspectives to help fifth-grade students to improve their basic and integrated science process skills.

1.5 Research Questions

Based on the review, the following research questions are formulated:

1. Do students in the peer scaffolding group perform more reflection than those in the individual group?
2. Do students in the peer scaffolding group engage in more DLL cycles than those in the individual group?
3. Do students in the peer scaffolding group perform better in basic science process skills than those in the individual group?
4. Do students in the peer scaffolding group perform better in integrated science process skills than those in the individual group?
5. Do DLL users in the peer scaffolding group perform better in basic science process skills than the SLL users?

6. Do DLL users in the peer scaffolding group perform better in integrated science process skills than the SLL users?
7. Do DLL users in the individual group perform better in basic science process skills than the SLL users?
8. Do DLL users in the individual group perform better in integrated science process skills than the SLL users?
9. Are there interaction effects between the treatment methods and the level of engagement in the game for basic science process skills?
10. Are there interaction effects between the treatment methods and the level of engagement in the game for integrated science process skills?

1.6 Research Hypotheses

H1: Students in the peer scaffolding group will report significantly higher reflection scores compared with those in the individual group.

H2: Students in the peer scaffolding group will report significantly higher engagement in DLL compared with those in the individual group.

H3: Students in the peer scaffolding group will report significantly better performance in basic science process skills compared with those in the individual group.

H4: Students in the peer scaffolding group will report significantly better performance in integrated science process skills compared with those in the individual group.

H5: The DLL users in the peer scaffolding group will report significantly better performance than the SLL users in basic science process skills.

H6: The DLL users in the peer scaffolding group will report significantly better performance than the SLL users in integrated science process skills.

H7: The DLL users in the individual group will report significantly better performance than the SLL users in basic science process skills.

H8: The DLL users in the individual group will report significantly better performance than the SLL users in integrated science process skills.

H9: The peer scaffolding method will significantly interact with the level of engagement in the game in basic science process skills.

H10: The peer scaffolding method will significantly interact with the level of engagement in the game in integrated science process skills.

1.7 Significance of the Study

Developing science process skills is a multifaceted problem. A number of studies emphasize the significant role of teachers in improving scientific thinking (Lawson, 1995; Miles, 2010). Students begin by exploring a new phenomenon to create disequilibria in their schema, and while the students are in a cognitively conflicted state, the teacher offers tentative answers or procedures that the students improve on by generating and testing alternative solutions or new arguments to reestablish equilibrium. This approach requires school administrators and teachers to engage actively in the development of the science process skills by advanced training for teachers or by providing laboratory facilities and supplies for students (Tifi et al., 2006) based on the belief that scientific thinking skills are better taught by an expert and in a formal setting instead of acquired independently by students.

Computer games provide an informal student-centered opportunity to overcome curricular and logistical obstacles to achieving inquiry-based learning (Honey & Hilton, 2011). Complex inquiry-based computer games serve as a new method for students to acquire knowledge and skills in a constructivist manner in which players can examine their ideas and receive feedback on their hypotheses and strategies without the intervention of teachers (Jong et al., 2010). Numerous studies show that games enhance children's cognitive development (Buchanan, 2003; Plowman, 2005) and in particular improve their higher-order cognitive processes (Pillay, 2003; Ko, 2003). Thus, this study employed the modified PBG model (Kiili, 2007) with peer scaffolding to explain how spontaneous playing can be connected to science process skills to enrich game-based learning. Learning from digital games is definitely in its infancy (Kafai, 2001; Kirriemuir & McFarlane, 2003; Squire, 2003), and any study on children's learning and digital gaming further illuminates the perception of this medium and its potential as an instructional technology tool (Gee, 2005; Squire, 2003).

The significance of this study is its potential contribution to the understanding of PBG with peer scaffolding as an inquiry-based model to improve science process skills among fifth-grade students.

1.8 Operational Definitions

Science Process Skills: This term refers to a set of broadly transferable abilities that are appropriate to many science disciplines and are reflective of the behavior of scientists. These skills are defined at two levels: basic skills that include observation, communication, classification, measuring with numbers, inference, prediction, using space and time relationship as well as integrated skills such as interpreting data, controlling variables, defining operationally, formulating hypotheses, and experimenting.

Single-Loop Learning (SLL)**:** SLL involves the use of prior knowledge and strategies to complete the challenge in the game. In playing the game, easier tasks that require basic science process skills such as observation, classification, inference, and prediction can be completed through SLL and are reflected by smaller number of points rewarded for completing the required task of the game.

Double-Loop Learning (DLL): DLL involves the formulation of advanced strategies to construct a new schema for knowledge and complete the challenge in the game. In playing the game difficult tasks that require integrated science process skills such as interpreting data, controlling variables, making hypotheses, and experimenting can only be completed through DLL and are reflected by larger number of points rewarded after completing all the tasks of the game. If a DLL level is not completed, students will be classified as having completed only the SLL level.

Reflection: This term refers to the processes of assessment and evaluation of the usefulness and appropriateness of the strategies and formulations to complete the tasks and challenges for every level of the game.

Peer scaffolding**:** This term refers to the advice, suggestions, and questions offered and raised by a partner in the group in finding the better solutions for the tasks in the game.

Level of engagement**:** Level of engagement in the game is measured by the number of reward points in each level of the game without any assistance. The points are recoded in two levels of SLL and DLL. DLL users have higher engagement in the game compared with SLL users.

1.9 Summary

This chapter began by presenting the considerable gap between knowledge of science and scientific thinking skills including basic and integrated science process skills. Then, by introducing computer games, emphasized to improve science process skills through digital games in a constructivist and student-centered manner to overcome curricular and logistical obstacles to achieve inquiry-based learning. The modified problem-based gaming model comprising main elements of SLL, DLL and reflection was proposed as the framework to explain the mechanisms of improving both basic and integrated science process skills through playing digital games. Peer scaffolding was considered as an additional external inputs to enhance the engagement level to the DLL. Ten research quotations have been derived from problem statement and 10 hypotheses were developed to find the mechanism of engagement in digital games through modified PBG with peer scaffolding to improve science process skills. The significance of this study was stated as its potential contribution to the understanding of PBG with peer scaffolding as an inquiry-based model to improve science process skills among fifth-grade students.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This literature review investigates the use of games in improving science process skills; the theories of game-based learning and their applications to promoting science process skills; the PBG model and its subdivisions including SLL, DLL, and reflection; and peer scaffolding as an additional external input to involvement in DLL. Previous research in this area is also summarized.

2.2 Digital Games and the Development of Science Process Skills

The International Game Developers Association (2005) reports that about 190 institutions in the United States alone, and 161 worldwide offered games for education (Fletcher, 2006). To have a comprehensive definition of games, considering the wide variety of definitions, it can be found that there is no single general definition due to different disciplines have different perspectives toward game. Whitton (2009) used the characteristics of games to provide an open definition of game as competition, challenge, exploration, fantasy, goals, interaction, outcomes, people or other individuals taking part in the playing, rules and safety. Games in this definition comprise at least three characteristics of all. This approach allows consideration and inclusion of a range of game-like activities that are interesting in terms of their educational value, but might not be considered to be truly games by some.

Digital games have been employed as experience-based instructional settings in a number of disciplines because of their potential to overcome the restrictions and limitations of conventional teaching methods (Ruben, 1999). According to the definition provided by Honey and Hilton (2011), digital games are informal contexts for fun with explicit rules and targets, providing appropriate feedback and attractive environments for players to interact. They have motivating features for catalyzing inquiry-based learning so that players can see the consequences of interacting in the context of the game (Honey & Hilton, 2011). Games have a potential for educational application because they provide environments that enable students to construct their own knowledge and experiences for themselves instead of absorb knowledge transferred by teachers (Vogel, 2007).

In the early 1980s, after the recognition of the Pac-Man game in the arcade genre, the arguments for employing games in teaching and learning emerged. Currently, the uses of video games in learning are different from those in the previous few decades. Although a number of technological improvements have been made to the games (e.g., more complex interfaces, dynamic player interaction, and 3D graphics), the main differences are due to the shift in the foundation of learning philosophy from behaviorism (Rachlin, 1991) to constructivism (Bruner, 1960; Papert, 1993; Piaget, 1964, 1970). As opposed to behaviorism, constructivism emphasizes knowledge construction by the learner (Jong et al., 2010). In the constructive approach, learning is not simply transferred from the video games, and the challenge is to engage the player in discussing the game and reflecting on it to construct knowledge (Egenfeldt, 2006; Clark et al., 2007). In this manner, learning is a cognitive and socio-cultural interaction in an engaging environment (Otting &

Zwaal, 2007). Further studies in the cognitive and socio-cultural features of games (Gee, 2003, 2005; Aylett, 2005; Prensky, 2001, 2006; Squire, 2005; Shaffer, 2006) argue about the educative opportunities offered by games (Jong et al., 2010).

Green and McNeese (2007) argue that, in playing digital games, students can use various skills such as strategizing and problem solving, and then develop critical thinking skills. In this regard, logical reasoning skills are employed in adventure games, and analytical skills are used in strategy games. Ellington et al. (1981) assert that science reasoning skills and general critical thinking skills can be developed through science-oriented games. In other words, science provides the context for the game and can be used to teach higher-order thinking skills. Hogle (1996) argues that, although games may not teach logic or reasoning skills, they do enable players to practice these skills. Stadler (1998) describes the use of the board game Black Box to teach scientific reasoning, specifically inductive and deductive reasoning. To win the game, students use inductive and deductive reasoning to generate hypotheses in a manner similar to how scientists work.

According to the US Committee on Science Learning of the National Research Council (2011), digital games deserve future investment and investigation to improve science process skills (Honey & Hilton, 2011). The committee states, "Games have the potential to advance multiple science learning goals, including motivation to learn science, conceptual understanding, science process skills, understanding of the nature of science, scientific discourse and argumentation, and identification with science and science learning" (Honey & Hilton, 2011).

Some studies investigated the use of digital games in promoting problem-solving skills in general and science process skills in particular. Sandford et al. (2006) conducted a survey to describe the processes of game-based learning among 924 primary and secondary school teachers and 2,334 secondary school students. Teachers answered questions about computer games in the classroom, and students answered questions about games in and out of the classroom. Three games (i.e., Knights of Honor, The Sims 2, and Roller Coaster Tycoon 3), in which the students had full control over the environment, were employed. The study found that both students and teachers considered playing computer games improved general problem-solving skills.

In another study, Barab et al. (2007) confirmed the positive effects of employing games to improve science process skills through Quest Atlantis, a serious game designed for science classrooms. In the game, each quest has entertainment and educational features. The quest involves investigating the reasons behind the declining number of fish in a park. A player engages in the problem-solving process as an avatar that can travel to places, speak with others, and carry out quests. During the game, small groups of students tried to solve the problem by interviewing people with different perspectives, collecting and analyzing data to extend a hypothesis about the problem, and then suggesting certain solutions.

Hickey, Ingram-Goble, and Jameson (2009) also used the 3D multi-user Taiga Park game, which is part of Quest Atlantic. The game was designed to engage 9-to-16-year-old students in educational tasks. A sixth-grade teacher was assigned to four classes. Two classes were taught by using Taiga Park, and two other classes were taught by using a custom textbook covering the same topics taught to another group within four weeks. The conceptual understanding and inquiry skills were measured using two assessments. The results of the study show significantly higher gains in both conceptual understanding and science process skills for the Taiga Park classes.

However, Ketelhut et al. (2006) employed the research-based educational game of River City but did not find any significant difference in content and science process skills between the experimental and control groups, although thoughtfulness of inquiry was significantly higher for the experimental group. In this research, the experimental group played River City, whereas the control group used the same content in their paper-based curriculum. In further analysis, Ketelhut et al. (2007) searched for evidence of inquiry in an assessment at the end of the treatment among a sample group of 224 students. In this part, students were asked to write a letter to the mayor. Letters by students playing River City reported significantly higher scores in overall quality than those of students in the control group. The experimental group was significantly better in formulating a hypothesis and in concluding.

Moreover, more evidence that links higher-order thinking and cognitive development to digital gaming has been found, which lends broad support to the use of games to improve science process skills. For example, Pillay (2003) argues that those who play games construct or develop schemata for knowledge. Players develop their expertise in recreational video games and more easily transfer their knowledge structures between different environments, especially computer-based environments. Pillay (2003) employed a strategy-adventure video game to investigate the cognitive processes involved in playing among secondary school students. The game promoted schema construction and development in students.

The game-based learning was studied by Kima et al. (2009) to investigate the effects of meta-cognitive strategies on problem solving ability and achievements. A Massively Multiple Online Role Playing Game (MMORPG), Gersang, was used. The sample was 132 ninth grade students who had never played the game. The study demonstrates that discussing game play with peers during break sessions positively affects the social problem solving abilities.

Alkan and Cagiltay (2007) made a case study of 15 undergraduates to examine, through eye tracking, learning experiences in playing video games. The students played an unfamiliar puzzle game and then answered some questions about their experience in playing. The students recognized the necessity for intelligence, problem-solving skills, and reasoning in solving the puzzles and preferred to play more complex action and strategy games. Alkan and Cagiltay (2007) concluded that the cognitive processes of players are altered by what happens in the game.

The above mentioned studies provide strong support for the use of digital games to promote science process skills. However, the mechanisms for improving such skills through digital games remain unclear and are discussed in the following sections.

2.2.1 Evaluating Commercial Video Games

Effectiveness in meeting educational objectives should be a factor in the choice of a video game for educational purposes (Fanetti, 2011). Ellington et al. (1981) report the advantage of using precise methods, such as cognitive and noncognitive tests and self-reports, to evaluate games over using anecdotal definitions. Hogle (1996) points out that, because games are cognitive tools, they must be evaluated in a cognitive context, presenting different issues about the evaluation of the effectiveness of games in education.

In analyzing games for education, surface and deep structure must be considered. Surface structure refers to the visible features of the game, such as graphics and sound, and deep structure refers to fundamental psychological mechanisms in the game and interactions between the game and the player (Gredler, 2004). In this regard, Rice (2007) developed an evaluation rubric for teachers employing commercial video games for educational purposes. This rubric, called the Video Game Higher-order Thinking Evaluation Rubric, consists of 20 yes-or-no questions highlighting the characteristics of games that make them more effective in teaching higher-order thinking skills. A score of 15 or higher, out of an achievable 20, is effective in encouraging higher-order thinking. However, Rice's rubric has no guideline based on age of learners.

2.3 PBG Model and Learning

Computer games have primary conditions for providing engaging environments for learning. Unfortunately, many educators who choose games for instructional purposes do not utilize the advantage of games as interactive media but