Effects of Knowledge Construction Tools on Students' Learning Patterns in Collaborative Game-based Learning Activities

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***Abstract*—In this paper, a collaborative game was developed by integrating a grid-based knowledge construction tool. Moreover, an experiment was conducted to examine effects of the knowledge construction tool-based gaming approach on students' behavioral patterns. From the experimental results, it was found that the students who learned with the knowledge construction tool-based collaborative game revealed significant behavioral patterns of "comparing and observing the learning targets" as well as "seeking clues and answers" on their own. This implies that integrating the knowledge construction tool into the collaborative educational game has great potential for fostering students' ability of applying what they have learned to deal with problems.**

Keywords—digital game-based learning, knowledge construction tool, collaborative learning, behavioral patterns

I. INTRODUCTION

Several researchers have questioned the impacts of game-based learning [1]; for example, Hong, Cheng, Hwang, Lee and Chang (2009) pointed out that poor design of educational computer games could lead to negative impacts on students' learning outcomes [2]. That is, it is crucial to integrate effective learning strategies or tools when developing computer games for educational purposes.

Among various learning strategies and tools, repertory grids have been identified as an effective knowledge construction tool for assisting students in collecting and organizing information as well as interpreting and comparing the acquired learning content [3, 4]. Nevertheless, integrating such a knowledge construction tool into game-based learning tasks is challenging work [5, 6]. Without proper integration of gaming missions and knowledge construction tools, students' learning outcomes could be disappointing. So far, few studies have been conducted to investigate how to properly integrate the knowledge construction tools into gaming scenarios or how to deal with the difficulty students face when learning with the knowledge construction tools. In addition, to the best of the researcher's knowledge, no study related to the investigation of the effects of knowledge construction tools on students' learning behaviors and patterns in educational games has been reported. This implies that it is important and necessary to explore the way of integrating effective knowledge construction tools into gaming scenarios and to investigate the students' learning behaviors in addition to their learning performance.

In this study, a collaborative educational computer game was developed based on a grid-based knowledge construction tool which aims to guide students to organize knowledge collaboratively for differentiating a set of target plants for the subject unit "Identifying the plants on the school campus," part of an elementary school natural science course. An experiment was conducted to examine the differences between the learning behavior patterns of the students who learn with the Knowledge construction tool-based collaborative game and those who learn with the conventional collaborative game-based learning approach.

II. LITERATURE REVIEW

A. Collaborative game-based learning

Several scholars have indicated that integrating games and learning content can strengthen students' learning motivation as well as situate them in a learning context with more interactions [7, 8]. In the past decade, various applications of digital game-based learning in school settings have been reported [9]. For example, Hwang, Sung, Hung, Huang, and Tsai (2012) developed a computer game to situate students in an adventure gaming context for learning the knowledge of plants in an elementary school natural science course [10]. Soflano, Connolly and Hainey (2015) employed a computer game to teach data manipulation language in a computer course [11].

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Several studies have reported the potential of computer games for promoting students' interactions with learning systems as well as improving their learning outcomes [12, 13]. For example, Dickey (2011) indicated that game-based learning environments are able to promote students' intrinsic motivation and curiosity [14]; Hwang, Chiu and Chen (2015) reported the positive effects of contextual game-based learning on students' learning performance in a social studies course [1]. Hsiao, Chang, Lin and Hu (2014) have further pointed out that learning via playing computer games has great potential for enhancing students' creativity tendency [15].

In the meantime, possible negative impacts of digital game-based learning owing to poor learning design have also been pointed out [3, 5, 10]. Collaboration is a widely adopted strategy for helping students deal with challenging learning tasks. In the past decade, various studies related to collaborative game-based learning have been reported [16]. For example, Marty and Carron (2011) reported the positive impacts of a collaborative online game-based learning system on students' learning motivation [17]. Sánchez and Olivares (2011) shared the experience of employing the collaborative game-based learning approach which could promote students' collaborative skills as well as their learning outcomes [18].

On the other hand, researchers have emphasized the importance of providing learning support or scaffolding for assisting students to effectively learn in a collaborative game-based learning environment [19]. Sung and Hwang (2013) further indicated the need to provide knowledge construction tools to guide students to discuss and learn during the collaborative game-based learning process [20]. Therefore, it is concluded that collaborative gaming could be a promising approach for helping students face challenging tasks. However, to help students organize what they have learned during the gaming process and their prior knowledge learned during the collaborative gaming process, the provision of knowledge construction tools needs to be taken into account in developing the learning activities.

B. *Knowledge construction tools*

Knowledge construction tools or Mindtools refer to computer systems that accompany students to learn in a higher order thinking manner, such as making inferences, organizing knowledge, analyzing data and solving problems. Among various knowledge construction tools, the systems that facilitate knowledge acquisition for developing expert-level systems that provide decision-making suggestions have been recognized as being potential knowledge construction tools for helping students organize and construct knowledge [21, 22] That is, the methods or tools to facilitate knowledge acquisition could be an effective knowledge construction tool for helping students organize what they have learned or experienced.

Among various knowledge acquisition approaches, the repertory grid method has been widely adopted in developing knowledge-based systems [21]. In addition, it has been adopted by several researchers as a knowledge construction tool that assists students to organize knowledge during the learning process [23]. A repertory grid is a table in which the columns represent concepts to be learned or targets to be identified, and the rows are the attributes for identifying the targets. As shown in Table 1, each attribute is represented by a trait and the opposite of that trait. For example, for the attribute "leaf shape," the trait could be "thin and long" and the opposite could be "round and flat." A 5-scale rating scheme is usually adopted for describing the relationships between the learning targets and the attributes. For example, to describe the leaf shape of plants on school campus, "1" might mean that "the leaf shape of the plant is inclined to thin and long" and "5" means that "the leaf shape of the plant is inclined to round and flat."

III. Knowledge construction tool-based Collaborative Game (MCG)

The Knowledge construction tool-based Collaborative Game (MCG) consists of two components. The first is the collaborative educational computer game implemented with RPG Maker, a role-playing game-development tool published by Enterbrain Incorporation; the second is the collaborative knowledge construction system developed with Google Sites. The former contains a learning material module, a storyline module, and a gaming material database; the latter provides a repertory grid and a discussion forum for the students.

A. *The Repertory Grid-based Collaborative Gaming Approach*

When playing the MCG, in addition to observing and identifying the target plants following the gaming storyline, each group of students needs to collaboratively collect the information of the target plants to develop their own repertory grid.

A total of five learning targets (i.e., five plants) are located in different parts of the game. The player can walk close to the targets to observe their detailed features. Moreover, there is a magician school, which provides supplementary materials of individual targets in the game. The player is allowed to read the materials at any time during the gaming process. There are also many gaming characters walking around in each gaming scenario. The player can talk to those gaming characters to derive hints or additional information for completing the gaming missions. When the player encounters problems, such as failing to complete a gaming mission or a question, an angel or a wizard will show up to provide some hints. The player can choose to follow the hints or refuse to accept the help. In addition, during the gaming process, the players in the same team can share information and knowledge related to the game and learning content via a discussion forum for completing the repertory grid as well as the gaming missions.

B. *Integration of the Gaming Storyline and Learning Content*

At the beginning of the game, there is a brief introduction to the background story, which is related to a fantastic adventure. A plant named Ali was transformed into a human 4.6 billion years ago and found some secrets in the world. He started a journey to help his family transform from plants to humans. The game consists of five main missions, each of which involves three challenges. There are several possible game endings.

C. Learning and Discussion Interfaces

Figure 1 shows the learning interface of the collaborative game-based learning environment of this study. The students play the game in teams of three or four members. Once the players collect all of the data about a plant and pass the relevant tests set by the monster, the plant can be transformed into a person. If the players fail to pass a test, an angel or wizard will try to give them some hints. The players can decide to follow the hints or not. In the meantime, following the storyline of the game, the students can collect the information needed to develop their repertory grid collaboratively via discussing with the group members, and modify the repertory grid via a shared interface.

Fig. 1. Learning interface for the experimental group

IV. Experiment Design and Procedure

A. Participants

The participants of the experiment were six classes of sixth graders of an elementary school in southern Taiwan. A total of 186 students participated in this study. The age of the students was 12 on average. Three classes were assigned to be the experimental group and the other three classes were the control group. Each of the groups included 83 students. All of the students were taught by the same instructor for the natural science course.

B. Experimental Process

Before the experiment, both groups of students took a three-week course on the basic knowledge of the plants, which is a part of the natural science course. Following that, the students in the experimental group learned with the collaborative educational computer game with the repertory grid approach; on the other hand, those in the control group learned with conventional collaborative game-based learning. The time for the students to complete their learning tasks was 120 minutes.

C. Coding Scheme for gaming behaviors

The coding scheme of the gaming behaviors was developed based on the gaming features of this study, as shown in Table 1.

TABLE I. THE CODING SCHEME FOR THE CONTENT ANALYSIS OF THE MCG GAME

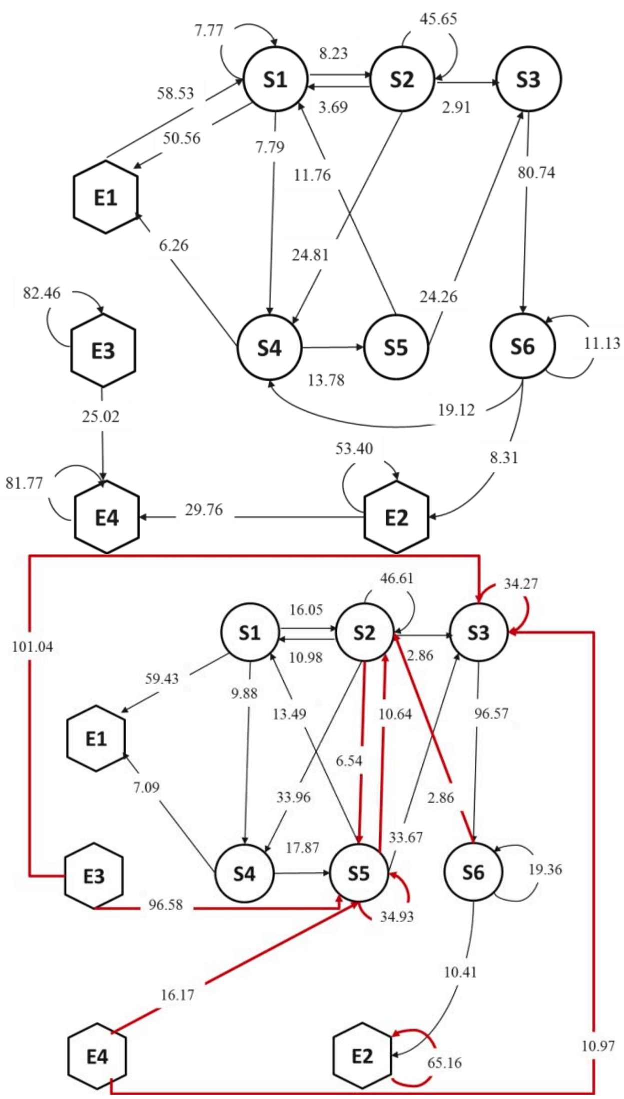
Code	Phase/content	Description
S1	Selection of a task	Choose or start a new gaming mission
S2	Observation	Go to the location of the learning target
S3	Comparison	Observe two learning targets by switching the player's location from one target to another
S4	Reading supplementary materials	Read additional materials related to the learning targets
S5	Clue search	Obtain some key clues.
S6	Correctly comparing a learning target	Correctly answer a multiple-choice question of the comparative test
E1	Reject challenges	Refuse to accept the opportunities for wining treasures in the game
E2	Decline assistance	Refuse to follow the hints provided by the gaming character when encountering difficulties in completing the gaming missions
E3	Incorrectly identifying a learning target/environment	Incorrectly answer a multiple-choice question of the basic test
E4	Incorrectly comparing a learning target/environment	Incorrectly answer a multiple-choice question of the comparative test

V. Experimental Results

By applying lag sequential analysis [24], the adjusted residuals table of the control group students' behavioral transitions was determined with n = 83, as shown in Table 3, in which the elements in the left-most column represent the starting behaviors, while those in the top-most row represent the subsequent behaviors. For each possible sequential pattern, a Z-value is calculated [25]. If the Z-value is greater than 1.96 it indicates that the behavior-sequence reaches the significant occurrence level ($p < 0.05$). For example, for the starting behavior S1, the Z-values for S1→S1, S1→S2, S1→S4, S1→S6 and S1→E2 are greater than 1.96; therefore, they are marked with a "*" to indicated the significance of the behavior sequence.

For the control group, there are 27 significant sequences among the 100 possible sequential patterns. Accordingly, the 27 significant sequences are then represented as a diagram of behavioral transitions. Similarly, the behavior sequences of the experimental group students were also analyzed. The behavior transition diagrams of the two groups are shown in Figure 2.

Fig. 2. Behavior transition diagrams for the control group (upper) and experimental group (lower).



It is found that frequent behaviors of S3 (Comparison) and S5 (Observation) could be the key reason why the experimental group had better learning performance than the control group. This can be found from the significant behavior sequences S3 (Comparison) → S3 (Comparison), S5(Observation) → S5 (Observation), E3→S3 (Comparison), E3→S5 (Observation), E4→S5 (Observation) and E4→S3 (Comparison). Moreover, the experimental group students showed a good learning habit; that is, they tried to seek clues when observing the learning targets. This can be found from the significant behavior sequences S2(Observation) →S5(Clue search) and S5(Clue search) →S2(Observation).

Another finding related to the behavioral patterns of the experimental group is that they would like to deal with the learning tasks on their own. This can be evidenced by the significant behavior sequence E2 (Decline assistance) →E2 (Decline assistance).

VI. Discussion and Conclusions

In this study, an integrated grid-based knowledge construction tool and collaborative game-based learning environment is proposed and a computer educational game has been developed based on the approach. Moreover, an experiment was conducted on an elementary school natural science course to evaluate the performance of the proposed approach.

From the experimental results, it was found that the students who learned with the knowledge construction tool-based collaborative game-based learning approach revealed more behavioral patterns of comparing and observing the learning targets as well as seeking and reading the supplementary materials than those who learned with the conventional collaborative game-based learning approach.

From these findings, it is inferred that the use of the grid-based knowledge construction tool in the collaborative gaming process provided a clear learning and gaming objective to the students as well as encouraged them to observe, compare and seek clues on their own, which could be the reason why their problem-solving awareness was improved. As suggested by Jonassen (2000), proper use of knowledge construction tools has great potential to foster students' higher order thinking skills [22]. On the other hand, using knowledge construction tools does not guarantee satisfactory learning outcomes; for example, the study of Charsky and Ressler (2011) showed that improper use of knowledge construction tools might lead to negative impacts on students' learning motivation and performance [16]. Therefore, the success of the knowledge construction tool-based collaborative gaming approach in this study implies that the repertory grid method has been properly embedded in the game-based learning process.

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