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UNFOLDING LEARNING BEHAVIORS: A SEQUENTIAL ANALYSIS APPROACH IN A GAME-BASED LEARNING ENVIRONMENT

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During the past two decades, conducting game-based learning research poses several predicaments. In particular, two primary challenges have been raised: the lack of long-term intervention in a real world and the lack of the revelation of learning process for understanding students' engagement. Hence, in order to overcome the two challenges gradually, a previous study developed a game-based learning environment, entitled My-Pet-My-Quest (MPMQ), for arithmetic practices. The MPMQ provides pet-keeping tasks and learning tasks, so that students can play the role of pet-keepers who can interact with their virtual pets and solve a series of small quests that sustain students' motivation and engagement. For understanding students' behaviors in the environment, two processes were carried out. This study first attempted to implement long-term intervention in an elementary after-school club as well as students' home, and then to analyze the learning process. Furthermore, this study adopted a sequential analysis approach, based on a designing framework, to help us examine and understand the each aspect of behaviors in students' learning and playing. These results can provide suggestions and references for the design of efficient game-based learning environments in the future.

Keywords: Game-based learning; sequential analysis; behavior.

1. Introduction

During the past two decades, the advent of divergent learning technologies has promoted many changes in the design of learning environments, such as online forums (e.g. Knowledge Forum (KF): see Scardamalia & Bereiter, 2006), multi-user virtual environments (MUVE) (e.g. Quest Atlantis (QA): see Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005), and educational game environments (e.g. ToonTown: see Dickey, 2007). So, the possible evolutionary trends of learning environments are multi-dimensions. Recently, educational game environments increasingly attract the attention of educators and researchers due to its positive influences on motivation and learning, especially on students' behaviors. The emergence of educational game environments has been influenced the epistemological shift toward positive behaviors by the impact and integration of game elements and learning content (Amory, Naicker, Vincent, & Adams, 1999; Chen, Liao, Chien, & Chan, 2011; Lim, 2008; Prensky, 2008; Rieber, 1996). Specifically, game-based learning environments could motivate learners to learn, and provide students with a great deal of learning opportunities to improve their learning (e.g. Barab et al., 2005; Gee, 2003; Prensky, 2001).

However, conducting game-based learning research poses several predicaments. In particular, two primary challenges have been raised as the empirical studies of game-based learning proved that inspiring the students' learning or motivation is impactful. One challenge is *the lack of long-term intervention in a real world (i.e. formal school courses)*. The authors examined six review papers about game-based learning (Dempsey, Rasmussen, & Lucassen, 1996; Emes, 1997; Hays, 2005; Randel, Morris, Wetzel, & Whitehill, 1992; Vogel et al., 2006; Wolfe, 1997), and learned that the dynamic in-game behaviors of students who immersed themselves in a game environment were difficult to be observed and recorded, especially in a long-term real world. Moreover, Ke (2009) indicated the problems that the empirical studies on instructional games were fragmented (Dempsey et al., 1996) and on the evaluation of games has been anecdotal, descriptive, or judgmental (Dempsey et al., 1996; Vogel et al. 2006), and the lack of longitudinal studies (Emes, 1997), while she revealed the use of digital games for learning purpose. In other words, most of previous studies conducted short-term exploratory research or many discrepancies between a real context and an experimental context. Most of these studies conducted in experimental contexts, and rarely in authentic contexts. In particular, the experimental studies are usually short-term interventions, which mean that students just operate a given system once or twice per week in at most three months. Conversely, the authentic studies usually implement long-term interventions, and students need to use a given system everyday in one or more years. We believed that the long-term studies (or called authentic studies) are everyday intervention in order to solve real problems of learning. Therefore, exploring a real world context to know about real problems and to support their long-term learning is becoming a critical issue.

Another challenge is *the lack of the revelation of learning process for students' engagement.* In recent years, most efforts of data collection have entailed learning outcome (e.g. questionnaire, pre-post-test comparison) more than learning process (e.g. individual interviews, field observations) for investigating motivations or effectiveness during students' learning/playing the educational games. In other words, many empirical studies of game-based learning targeted only at the exploration of learning outcomes (i.e. what do students acquire?) rather than learning process (i.e. how do students learn?). In particular, many of past studies appreciated the learning outcomes in order to understand what could improve the students' cognitive/affective aspects in game-based learning environments. On the other hand, only a few studies focused on understanding how to facilitate the learning process, especially for students' positive or negative behaviors in game-based learning environments. In fact, learning outcomes and learning process are both equally important to understand students' learning. Otherwise, the understanding of what/how the effects of game-based learning is limited. Besides, these empirical studies had deficiencies in understanding student behaviors of interactions in a game-based learning environment. Therefore, revealing the learning process of educational digital games in order to improve students' learning becomes a challenging issue.

Hence, our research team developed a game-based learning environment, entitled My-Pet-My-Quest (MPMQ) (Chen, Liao, & Chan, 2010; Chen, Liao, Cheng, Yeh & Chan, in press), for arithmetic practices in order to overcome the two challenges gradually. To achieve this goal, two processes were carried out. This study first attempted *to implement long-term intervention* in an elementary after-school club as well as at students' home, and then *to analyze the learning process* to understand students' behaviors. The system, a web-based pet-keeping environment where virtual characters represent learners' open learner models (Bull & Kay, 2007), provides pet-keeping tasks and learning tasks. More specifically, in the environment, students can play the role of pet-keepers who can interact with virtual pets and solve a series of small quests that sustains students' motivation and engagement. Furthermore, this study adopted a behavior analysis approach, based on a designing framework proposed by Amory (2007) and Dickey (2007), to examine and understand the each aspect of behaviors in students' learning and playing. Additionally, process lag sequential analysis (or called sequential analysis) (Bakeman & Gottman, 1997) was used to analyze the process pattern of students' learning. Subsequently, the results of the sequential analysis provide probes and insights into how the students' learning behavioral patterns in the game-based learning environment. Furthermore, these results can also provide suggestions and references for the design of efficient game-based learning environments in the future.

To summarize, the objectives of this study contain two aspects: *implementation* aspect, which is to utilize a ''game-based learning'' activity in an elementary after-school club and at students' home, and to record the learning process; and, *analysis* aspect, which is to use sequential analysis to investigate students' learning sequential behavioral patterns in a game-based learning environment.

Table 1. The influence of three design elements.

	Descriptions	Influence
Character design	Creating the multiple virtual characters of different personalities	Enlarging the students' social interaction
Narrative environment	Applying the diverse storylines with many locations	Deepening the students' immersion
Small quests	Developing a series of learning tasks with colorful scripting	Sustaining students' motivation

2. The Design of Game-based Learning Environment: My-Pet-My-Quest

Dickey (2007) proposed that the three elements of the design of an educational game environment are the character design, the narrative environment, and the small quests, to support intrinsic motivation, see Table 1. In a game-based learning environment, students create a virtual character, and then choose one from a variety of initial characters. In particular, students customize their character by choosing from a limited number of traits, skills, adornments and attributes. Moreover, this environment contained thousands of short narrative storylines. These storylines are usually embedded in a serious of small quests in the form of a non-player character (NPC) posing a short narratives in which they request the aid or assistance of the students' character (or called avatar). These short narratives provide students with opportunities for interaction with other virtual characters or peers.

The MPMQ environment design contains three main elements: *the virtual character design*, *the narrative environment*, and *the small quests (including learning contents)* (Amory, 2007; Dickey, 2007). In the MPMQ environment, each student adopted a virtual character role and played the various games, and participated in learning tasks. Throughout many short narrative storylines, students continually enhanced their character's skills and attributed by participating in a series of small quests in a game-based learning environment. All quests supported students' motivation in various ways. The virtual character design provided the virtual character with different personalities in order to enlarge the social interaction between real students and virtual characters. The narrative environment provided diverse story descriptions and five locations in order to deepen the students' immersion in game world. The small quest provided a series of learning tasks with colorful scripting in order to attract students' attention and sustain students' motivation.

Table 2. The design of virtual characters.

	Virtual Character	Role	Description
Student	Avatar (PC)	Pet-keeper	The students played a PC of "avatar" role, named pet-keeper.
Computer	Virtual Pet (NPC)	My-Pet	The computer controlled a NPC of "virtual pet", named My-Pet.
	Virtual Creature (NPCs)	Informer/ Entruster	The computer controlled NPCs of "virtual creature", named informer or entruster.

*PC = player-character, NPC = non-player-character, NPCs = non-player-characters

2.1. *Virtual character design*

In MPMQ environment, the design of virtual characters (VCs) focuses on three virtual characters—an *avatar*, a *virtual pet*, and *virtual creatures*—that are used frequently in game-based learning environment, see Table 2. Each student played an avatar (a player-character), who was a pet-keeper, see Figure 1. The pet-keeper nurtures a virtual pet. The computer controls a virtual pet (a non-player-character), named My-Pet. The game goal of the pet-keeper is taking good care of his/her My-Pet. The computer controls virtual creatures (also non-player-characters), named an informer and an entruster. The informer will inform the pet-keeper of where quests need to solve. The entruster will entrust the pet-keeper with quests.

A My-Pet has some numerical attributes to show its status, such as, energy, mood, and effort. The "energy" and "mood" attributes mean the interaction between My-Pet and the pet-keeper. The two attributes could be improved through feeding and playing with My-Pet, respectively. When the pet-keeper feeds the My-Pet, the "energy" attribute would be increased. Similarly, when the pet-keeper plays with the My-Pet, the "mood" attribute would be increased. To take good care of My-Pet, the pet-keeper needs to buy food and goods by EduCoins (as virtual coins in game-based learning environment). The EduCoins could be earned from quests. In other words, each student is guided to conduct

Figure.1 Snapshot of the Pet-keeper, My-Pet, Informer in the My-Pet-My-Quest environment.

Table 3. The design of narrative environments.

Categories	Location	Description
To undertake tasks	pet-forest, bright city, and devil tower	Pet-keepers will undertake tasks.
To buy something	shopping street	Pet-keepers can buy something for My-Pets.
To interact with peers	pet-arena	Pet-keepers interact with peers.

the quests for his/her pet. The informer and entruster also prompt him/her to commit the various quests.

2.2. *Narrative environment*

In the MPMQ environment, the design of narrative environments focuses on places—*for undertaking tasks*, *buying virtual products*, and *interacting with peers*, see Table 3.

The places were divided into three types: pet-keepers could undertake tasks in a pet-forest, a bright city, and a devil tower; pet-keepers could buy something for My-Pets in a shopping street; pet-keepers could interact with peers in a pet-arena. Pet-keepers could inspect the status of pet-keeper and the My-Pet. The My-Pet inhabits in a backyard, which is one of locations in the "island" game world. The pet-keepers could go to the shopping street to buy pets' food and goods, as well as to conduct accepted quests in the forests. In addition, the pet-keepers also could control their own My-Pets to interact with peers in the pet-arena, see Figure 2.

2.3. *Small quests*

In the MPMQ environment, small quests are designed for developing appropriate learning activities that include *a task description*, *specific task goals*, *learning contents*, and *rewards*, see Table 4.

When a pet-keeper conducts a quest in the forests, the pet-keeper will meet an

Figure 2. Snapshot of the game world of My-Pet-My-Quest.

Table 4. The design of small quests.

	Categories	Description
Scripting	To inspect task description	The entruster tells the pet-keeper information about how to complete the quest and what the rewards are.
	To understand the specific task goals	
Learning	To accomplish the tasks of learning contents	The pet-keeper needs to accomplish the quest for earning the rewards.
	To gain rewards	

entruster who appears with different requests for help. The entruster then tells the pet-keeper information about how to complete the quest and what the rewards are. That is, the pet-keeper needs to accomplish the quest for earning the rewards, such as EduCoins.

Figure 3 shows the snapshot of a quest entrusted by an entruster. The entruster tells the pet-keeper that there are a series of quests about a mathematical festival. The pet-keeper can conduct these quests. For example, the entruster offers the first quest about mathematical basic computation. The quest goal is to do multiplication exceeding the given threshold. These small quests that are implemented in the MPMQ are according to the criteria of the national curriculum in Taiwan for third-grade elementary school mathematics, such as calculation fluency and conceptual understanding, see Figure 4.

3. Methods

3.1. *Research design*

The participants were 29 nine-year-old third-grade students (14 males and 15 females) from an elementary school in Taiwan. Each participant used a small netbook (a small portable laptop computer with wireless capability) to practice the math problems about basic computation in a game-based learning environment. The experiment using the MPMQ environment was conducted in a classroom of the elementary school and

Figure 3. Snapshot of the quest entrusted by an entruster.

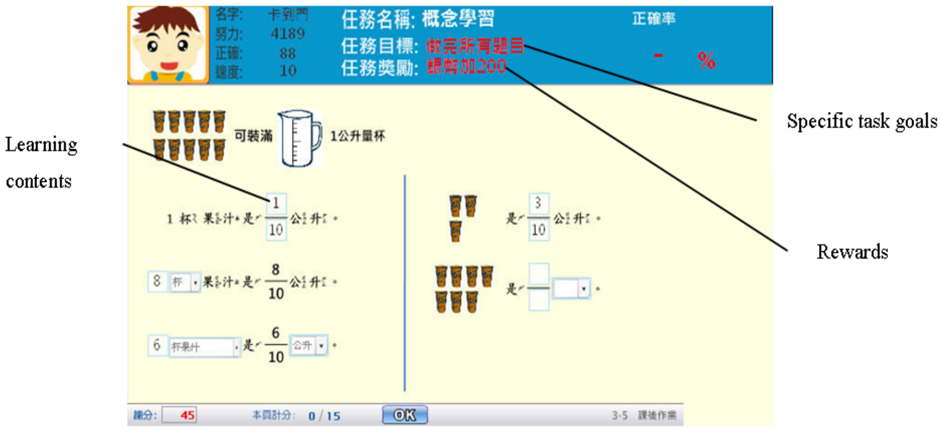


Figure 4. An example of small quest in My-Pet-My-Quest environment.

students' home over a period of one year. In other words, the experiment implemented a long-term intervention in an authentic educational field. It should be noted that this paper only analyzes the data in the first six months, which was divided into two phases: summer school phase, and after-school club or students' home phase.

Firstly, in order to make participants familiar with using the small netbooks and manipulating the game-based learning application, the instruction session was conducted for 40-minutes each day. During the 5-day period of summer school from 8/11 to 8/18 in 2009, students could access the MPMQ environment and browse a list of all functions. The main point of this activity was to make students know correctly how to use small netbooks for avoiding the negative influence of unfamiliarity with the devices in the study.

Secondly, authors implemented a ''game-based learning'' activity in an elementary after-school club. During the 120-day period of the after-school club from 9/01 to 12/31 in 2009, students could nurture the virtual pets and practice math problems about basic computation in the MPMQ environment. The students used the small netbooks for approximately 30 or 40-minute sessions each day in the four months. During this period, two graduate students (both were majoring in learning technologies) sometimes were employed as teacher assistants to observe the students' usage and feedback. Additionally, the students also could use the small netbooks not only at school but also at home.

3.2. *Coding scheme of the MPMQ environment*

The purpose of this study is to understand the students' behavioral process of game-based learning in a long-term real world. In order to understand students' learning and playing behaviors patterns in the game-based learning environment, the designing framework proposed by Amory (2007) and Dickey (2007) was modified for this study.

The study adopted a sequential analysis approach in which coding scheme is divided into five categories (as shown in Table 5), and each category represents a type of

Table 5. Coding scheme for students' learning and playing behavioral patterns.

Game designing framework	Categories (Codes)	#Event	Descriptions
Virtual character design	Nurturing (N)	#101	To examine the status of pet-keeper
		#102	To examine the status of My-Pet
		#103	To examine the items
		#104	To examine the equipments
Narrative environment	Game World (GW)	#107	To move the island game world
		#108	To move the shopping street
		#109	To move the pet-forest
		#110	To move the bright city
		#111	To move the devil tower
	Interaction (I)	#112	To interact with peers
Small quests	Scripting (S)	#106	To inform the pet-keeper about quests
		#128	To entrust the pet-keeper with quests
	Learning (L)	#129	To start with the task
		#105	To examine the history of tasks

students' learning or playing behaviors pattern. Different learning behaviors were defined in order to code the students' actions and allow further sequence analysis.

According to this designing framework, each code represents a specific behavioral process of students: nurturing (N) in virtual character design, game world (GW) and interaction (I) in narrative environment, as well as scripting (S) and learning (L) in small quests, respectively. For examples, students examined their status or inspected their My-Pet's status (N); they moved around different places (GW); they interacted with peers in pet-arena (I); they received the entruster's information about how to complete the learning quest and what the rewards were (S); and they accomplished the learning quest and earned the rewards (L). We divided these specific behavioral processes into two parts: *supported learning codes* (including N, GW, and I), and *sustained learning codes* (including S, and L). For the former, the game activities of nurturing, playing and interaction may engage students in learning activities. For the latter, students make commitments in the scripts, which may facilitate students to do learning tasks persistently. After they finish the tasks, they may get rewards, which can be used in the game activities. Hence, these codes initiate a positive learning cycle.

3.3. *Sequential analysis approach*

In recent years, some researchers (Bakeman & Gottman, 1997; Jeong, 2003, 2005; Jeong & Davidson-Shivers, 2006) developed lag sequential analysis (LSA) or called sequential analysis that explored the co-constructive knowledge of interaction in online discussion forums (Jeong, 2005) and computer-supported collaborative argumentation (Jeong &

Davidson-Shivers, 2006), because the LSA could process interaction data to present different data representations and to unpack different types of interactions. Kapur (2011) also argued that "LSA revealed significant temporal patterns in CSCL group discussions that the commonly used "coding and counting" method could not reveal." This means that LSA not only examines the frequencies of learning behaviors, but also reveals the orders of learning behaviors.

Hence, this study followed the above ideas and adopted a sequential analysis to investigate students' learning behavioral patterns. The sequential analysis tool is possible for us to understand deeply the interactions and behaviors among students in a game-based learning environment with a real classroom. In the future, the diversification and plenty of game-based learning environments possibly emerged from the computer-supported collaborative learning (CSCL) field. Furthermore, there are enormous potential opportunities of how this approach could be integrated with existing game-based learning or interactive learning systems. More specifically, such approach also could monitor, detect, and enhance dynamic students' behaviors in game-based learning environments.

The sequential analysis was first applied to explore the students' online behaviors of playing and learning in a game-based learning environment. The behavior analysis approach was divided into five steps: *collecting*, *defining and classifying*, *preparing*, *computing*, and *interpreting*. These steps are modified from Jeong (2005).

Step 1: Collecting a series of actions of students' behaviors in the game-based learning environment (GBLE). Students' behaviors generated from daily solving a variety of learning tasks and game activities. A remote server was set up in order to collect the log data of the students' practice. All behaviors of data were automatically recorded in the database of the MPMQ. Besides, each student was also observed to keep the observation comments (Taylor & Bogdan, 1998).

Step 2: Defining the students' behaviors—including Nurturing (N), Game World (GW), Interaction (I), Scripting (S), and Learning (L), and classifying these behaviors. As mentioned earlier, this study defined the students' behaviors based on a designing framework proposed by Amory (2007) and Dickey (2007), and then the computer program automatically classified these students' behaviors into the five categories of codes, to help us examine the each aspect of behaviors of students' learning and playing.

Step 3: Preparing data for analysis according to variables (as categories or codes) under investigation. This study processed the data of students' behaviors in the sequential analysis approach. The Discussion Analysis Tool (DAT, Version 1.80n, retrieved from http://myweb.fsu.edu/ajeong/dat/) has been developed by Jeong (2005) at Florida State University and used to parse out these codes of students' behaviors from the database of the MPMQ.

Step 4: Computing transitional probabilities, Z scores and transfer state diagrams. This study applied DAT to analyze these codes in order to compute transitional probabilities, conduct Z scores, and draw transfer state diagrams, because Jeong (2005) indicated that "DAT supports the analysis of mean response scores by outputting the necessary numerical data for computing and testing mean response scores in statistical analysis programs like SPSS" (p. 379).

Step 5: Interpreting the transitional probabilities for interaction behavior patterns and transfer state diagrams. This study attempted to propose a meaningful interpretation of interaction patterns revealed from the sequential analysis at game-based learning environment. These interpretations could provide suggestions and references for the design of efficient game-based learning environments in the future.

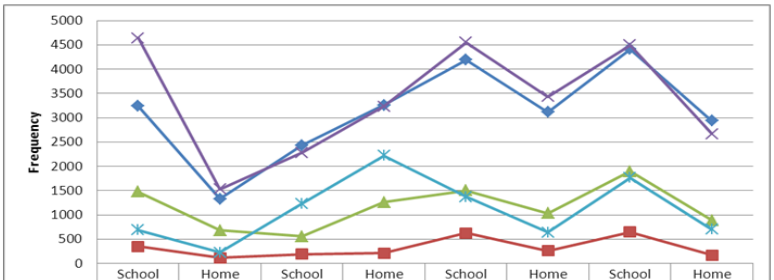
This is a visual way of capturing process data for gaming platforms by a sequential analysis approach. We attempted to explore a dynamic process for students' behaviors in game-based learning environment during four months in an authentic school environment.

4. Findings

The following two subsections describe both quantitative and qualitative results. Firstly, we started with the statistical distribution of students' participations in the MPMQ environment. Secondly, we reported the dynamics of students' behavior patterns analysis for interpretation of the LSA graphical representation.

4.1. *Distribution of students' participations in the MPMQ environment*

These codes (a total of 72,466 behavior codes) of 29 students were collected from the students' actions during the period of the MPMQ environment. Figure 5 represents the distribution of students' learning and playing behavioral patterns — nurturing (N), game world (GW), interaction (I), scripting (S), and learning (L) — that are each student's



	September		October		November		December	
	School	Home	School	Home	School	Home	School	Home
GW	3237	1332	2430	3261	4194	3115	4411	2939
I	348	115	193	214	629	263	644	168
L	1472	682	559	1262	1501	1033	1898	891
N	4642	1530	2279	3234	4548	3435	4495	2665
S	691	229	1230	2217	1370	640	1766	704

Figure 5. The distribution of students' learning and playing behavioral patterns.

actions during four months.

Figure 5 shows that the trend of categories (codes) was stable and slowly increasing on most the period (including school and home), except October. Because the school had three possible cases of H1N1 in October 2009, the school shut for a week which led to a decreasing frequency of each category at school and an increasing frequency at home. We also found that students highly frequently interact with the virtual characters (N) and the narrative environment (GW); students gradually increasingly interact with peers (I); and students' frequency on participating in the learning tasks (L) is higher than that on inspecting the task description (S) in Figure 5. These phenomena showed that the MPMQ has a potential to sustain the motivation of students for learning.

In order to reveal how these behaviors intertwined among students with peers and learning environment, we need further examination with LSA to uncover the behavioral patterns of the students as an MPMQ environment.

4.2. *The dynamics of students' learning behavior patterns analysis*

Before the students' learning behavioral patterns are interpreted, the relevant concepts of transfer state diagrams are described first. This paper takes the students' data in the school in September as an example. This example adopts the DAT to compute and examine transitional probabilities (see Table 6), and to draw the transfer state diagrams of significant sequences (see Figure 6).

More specifically, in Table 6 every row indicates one of starting students' behaviors; and every column indicates one of follow-up students' behaviors. This paper also adopts that the Z-score (higher than 1.64) statistical tests to identify these transitional probabilities and to indicate the behavioral sequences continuity from a certain row to a certain column has reached significance ($p < 0.05$: see Jeong, 2003, 2005). The significant sequences indicates the transfer state diagrams of transitional probabilities shown in Figure 6. In Figure 6, every circle represents one of students' behaviors (N, GW, I, S, and L) while the numerical values in the lines between two circles represent the probabilities of behavioral transfer; the arrow indicates the direction of transfer for each sequence while the thickness indicates the level of significance.

Table 6. The transitional probabilities of learning behavioral patterns in the school in September.

	N	GW	I	S	L
N	.77*	.19	.00	.00	.04
GW	.15	.56*	.09*	.17*	.03
I	.33	.52*	.12*	.01	.03
S	.41	.29	.03	.18*	.10*
L	.28	.22	.00	.00	.50*

$p < 0.05$ (Z-score = 1.64)

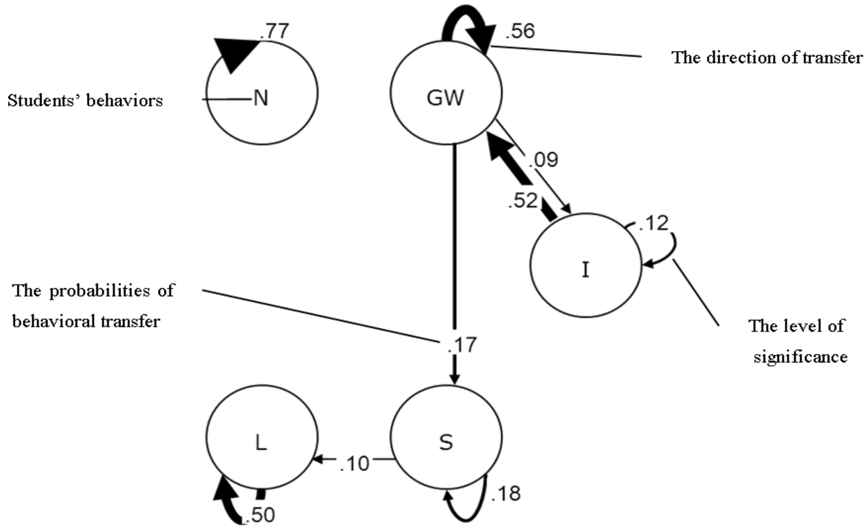


Figure 6. Transfer state diagrams of students' learning behavioral patterns in the school in September.

This initial analysis in Figure 5 and 6 was very helpful in interpreting the results of LSA in Figure 7. Figure 7 shows the significant sequences on behavioral transfer; the graph shows eight behavioral transfer state diagrams of 29 students at school and home during four months.

Figure 7 shows that each behavioral transfer state diagram can further be divided into three patterns: virtual characters (N), a narrative environment (GW and I), and small quests (S and L). First, the sequential learning behavioral patterns showed that most students were engaged in interacting with different *virtual characters*, such as playing the role of pet-keeper, nurturing their My-Pets, and interacting with the informer or entruster (*N→N*). Second, the sequential learning behavioral patterns represented that most students participated frequently in the *narrative environment*, such as immersing in the game-based learning environment (*GW→GW*), watching the storyline of learning tasks (*GW→S*), and interacting with peers (*GW→I, I→I, I→GW*). Finally, the sequential learning behavioral patterns indicated that most students participated frequently in the *small quests,* such as understanding the specific task goals and accomplishing learning tasks (*S→S, S→L, L→L, L→S*).

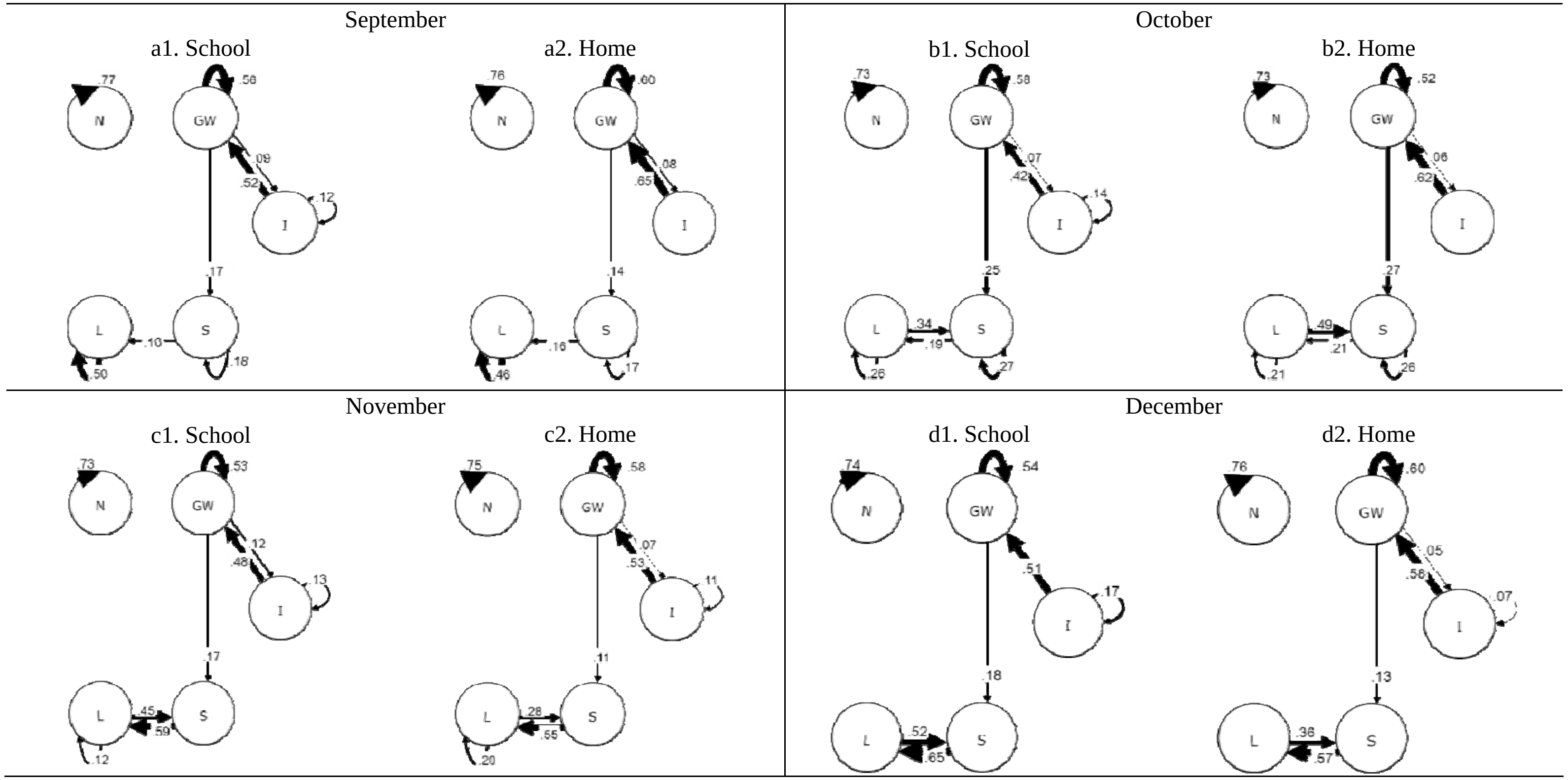


Figure 7. The behavioral transfer state diagrams of students at school and home during four months.

N: Nurturing; GW: Game World; I: Interaction; S: Scripting; L: Learning

In this MPMQ environment, the virtual character design and narrative environment pushed students to pursue the small quests. The small quests tend to reinforce the interaction of students with virtual characters in the narrative environment. These sustained learning codes (S, and L) are underpinned by solid progresses (N, GW, and I) in the game-based learning environment. In particular, the interaction of students with the virtual characters, the narrative environment, and the small quests in this MPMQ environment motivates them to keep learning and to continue to participate in learning activities. These interactive processes may help students sustain motivation. This means that these supported learning codes (N, GW, and I) and sustained learning codes (S, and L) create a persistent cycle. In order to interpret how these sequential patterns emerged among students, we further examined these behavioral transfer state diagrams across time and place, see Figure 7 again.

4.2.1. *Virtual character design*

First, we discuss the design of virtual character. We found that these behaviors of the interaction with different virtual characters were extremely stable by the numerical values in these diagrams (e.g. $N \rightarrow N$, September: 0.77, 0.76; October: 0.73, 0.73; November: 0.73, 0.75; and December: 0.74, 0.76). Additionally, the authors observed that most students gradually formed an emotional attachment to their My-Pets after being engaged in nurturing and being attentive to them; they would also discuss that the informer and entruster told them about new small quests. The interview protocols also revealed students' perception of the My-Pet, such as, "*I could feed it, and it would wag its tail after eating something. It was so cute*" (#s21). These data indicated that students could build close relationships by interacting with their My-Pets or other NPCs. Students paid close attention to their My-Pets, took good care of them, bought medicine for them, nurtured them and played with them at school and home.

4.2.2. *Narrative environment*

Next, we discuss the design of the narrative environment. We found that most students continued to participate in the game world (e.g. $GW \rightarrow GW$, September: 0.56, 0.60; October: 0.58, 0.52; November: 0.53, 0.58; and December: 0.54, 0.60) and sometimes participated in and watched the storyline of learning tasks (e.g. $GW \rightarrow S$, September: 0.17, 0.14; October: 0.25, 0.27; November: 0.17, 0.11; and December: 0.18, 0.13). This means that the MPMQ could provide the sticky information and facilitate the learning intention of students by joyful, immersing, and engaging environment.

Regarding interaction with peers, we found that most students can interact with peers (e.g. $I \rightarrow I$, September: 0.12, 0; October: 0.14, 0; November: 0.13, 0.11; and December: 0.17, 0.07). In statistical perspective, most interactions among students in pet-arena happened at school, not at home on the MPMQ environment in September and October. Subsequently, the probabilities of students' interaction with peers at school were stable while these interactions at home were happened in November and December. Besides, the authors also observed that some students can negotiate an appropriate time with peers to join the interactive competition together. These data showed that the probabilities of interactions were increased and had positively developed. Additionally, we also found that most interactions happened once a day. Students had high probabilities to go back to the game world, and then they could not interact with peers (e.g. $GW \rightarrow I$, September: 0.09, 0.08; October: 0.07, 0.06; November: 0.12, 0.07; and December: 0, 0.05; and $I \rightarrow GW$, September: 0.52, 0.65; October: 0.42, 0.62; November: 0.48, 0.53; and December: 0.51, 0.58). This means that the MPMQ should be encouraged to develop interactive elements that will play a leading role in the future and to provide a wider range of interactive forms in game-based learning for students.

4.2.3. *Small quests*

Finally, we discuss the design of small quests for the influence of students' behaviors. Regarding scripting, we found that some students just watched many descriptions of story, did not practiced learning tasks in September and October, while they did not do these gradually in November and December (e.g. $S \rightarrow S$, September: 0.18, 0.17; October: 0.27, 0.26; November: 0, 0; and December: 0, 0). In other words, students can complete these small quests under combining the scripting and the learning tasks in lately two months. Regarding learning tasks, we found that a few students continuously practiced the learning tasks of the day in September, and then the numbers of learning task decreased later (e.g. $L \rightarrow L$, September: 0.50, 0.46; October: 0.26, 0.21; November: 0.12, 0.20; and December: 0, 0). This data means that the students did not practice excessive tasks; they balanced the attraction of both parties: learning and gaming activities.

Regarding scripting and learning tasks, we found that most students, through the scripting, led to learning gradually (e.g. $S \rightarrow L$, September: 0.10, 0.16; October: 0.19, 0.21; November: 0.59, 0.55; and December: 0.65, 0.57; $L \rightarrow S$, September: 0, 0; October: 0.34, 0.49; November: 0.45, 0.28; and December: 0.52, 0.36). Besides, after the most learning activities, the authors observed that the students would continue to discuss the descriptions of stories and compare their answering status with each other. Classmates would also sometimes consult and teach each other how to perform difficult tasks. The authors also discovered that a few students spent a lot of time solving her quests in the MPMQ every day. The interview protocol is as follows: "*I like to achieve a lot of quests. Besides, we also discussed how to answer the difficult question* " (#s29).

This means that the strategy of quest-driven learning creates a positive cycle. Furthermore, the desire for accomplishing small quest may facilitate and sustain learning motivation. The strategy is to enhance and transform the learning process by skillfully interweaving learning and gaming to create a new environment. In other words, the MPMQ environment provides an interchange between learning activities and games. In this easily accessible and active environment, students' willingness to learn may be enhanced.

5. Discussions

Next, we discuss the academic and practical development of game-based learning environments (GBLEs), such as research and design and methodologies.

5.1. *Enhancing learning stickiness*

We define the phenomenon that student continuously engage in learning activity as learning stickiness. The authors also argue that sustaining motivation is a critical point for transforming learning through the use of digital games for educational goals. Successful learning often needs constant efforts and perseverance for a long period of time. The aforementioned findings showed that the use of the MPMQ would bring many benefits and opportunities for students' learning. This study developed two design strategies under the game-based learning approach: *pet-nurturing strategy* and *quest-driven learning strategy* in order to enhance learning stickiness and sustain motivation. The former, pet-nurturing strategy, could promote the students to care for their My-Pets (Liao, Chen, Cheng, Chen, & Chan, 2011). While students want to complete the game, learning must take place in the form of game-playing. The game world leads to learning activities and keeps the students' motivation. Ultimately, the students could build a long relationship with their My-Pets. The latter, the quest-driven learning strategy, aims at blending learning tasks by game quests (Chen et al., in press). Through the scripts, students are guided to know how to help the NPCs by completing the given game tasks. Meanwhile, the students could get rewards from the successful completion of the game tasks.

5.2. *Future directions: Incorporating sequential analysis approach into GBLEs*

This study adopted the sequential analysis approach in order to understand the students' behaviors in a game-based learning environment. In other words, the analysis of records can be a valuable tool for developing a set of online evaluation mechanisms (Kapur, 2011). Furthermore, we come up with three future directions in which revealing the students' behavior research could be implemented.

First, we should incorporate the tool-based sequential analysis with the game-based learning environment. Subsequently, the GBLE systems can monitor and detect dynamically whether students' actions are good or bad habits; the GBLE systems can also actively diagnose students' negative behaviors and trigger corrections for their actions.

Second, we should actively provide the parents and teachers with suggestions in order to guide the students through the learning difficulties and facilitate the students' motivation by positive feedback and rich responses. Parents and teachers will understand the students' negative behaviors and provide the appropriate guidance and feedback for students by the tool of sequential analysis.

Final, we should integrate into virtual character technologies, the sequential analysis tool, and the game-based learning environment. We can extensively develop and exploit the sophisticate educational agents (e.g. learning companion: see Chou, Chan, & Lin,

2003) or intelligent agents (e.g. NPC, non-player-character) that encourage or facilitate students to engage in the diverse learning tasks in a game world. By implementing the above, we will improve the design of the game-based learning strategies and understand the behaviors of students in a learning environment.

6. Conclusions

This is the first study of a game-based learning environment which adopts a sequential analysis approach for revealing students' behavior data in a long-term real world. The study focuses on reporting the findings of behavioral patterns among students in the MPMQ environment by using a sequential analysis approach with field observation. First, the findings indicated that the trend of students' behaviors was gradually increased during most of the period (including in school and at home). This revealed that the MPMQ environment could sustain the motivation of students for learning during one semester. Second, most students could build close relationships by interacting with their My-Pets, which implied that the students took care of their My-Pets very much. Third, most students positively participated in the game world and interacted with their peers gradually. This meant that the probabilities of interactions were increased and had positively developed. Finally, the strategy of quest-driven learning created a positive cycle, which suggested that the strategy could enhance and transform the learning process by skillfully interweaving learning and gaming to create a new environment.

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