Yang, J. C. et al. (Eds.) (2018). Proceedings of the 26th International Conference on Computers in Education. Philippines: Asia-Pacific Society for Computers in Education

Investigating Effects of Game-based Design Mechanisms on Learners' Reasoning Ability: A Cluster Analysis

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Abstract: This study examined the effect of game-based design strategies and auxiliary mechanisms on learners with varied cognitive styles (field dependence-independence, FD-I). It carried out an empirical study on the sixth graders of an elementary school in southern Taiwan. The following research questions were investigated through analyzing gaming behavioral data: (1) With respect to the improvement of reasoning ability, has the reasoning ability of the experimental group significantly improved compared to that of the control group? (2) Based on the game design mechanisms used in this study, does the design mechanisms of adaptive reasoning games be able to correspond with the gaming behaviors of FD-I learners? The results showed that in the reasoning ability pre-tests and post-tests, there was significant improvement in the reasoning ability of the FD (N=30, p=.017<.05) and FI (N=29, p=.014<.05) groups that had participated in the reasoning activities, while that of those who did not take part in the activities showed no significant improvement. These results confirm that the main principle, FD-I-oriented design strategy, formulated in planning and developing the reasoning game of "Dio's Wonderland Adventure" have substantial contribution in improving students' reasoning ability. With respect to the design strategies, they were mainly based on the behavioral preferences of FD-I students in information acceptance, information experience, and organizing information; and the seven design strategies were employed to develop a game model suitable for FI and FD.

Keywords: Game-based Learning, Cognitive Style, Reasoning Ability, Clustering Analysis, Adaptive Reasoning Game

1. Introduction

While learning takes place in classrooms, playing often provides students with another important channel for informal learning. Game-based learning strategies that combine digital games, learning contents and learning activities have already drawn the attention of researchers and educators (Gee, 2003; Hwang & Wu, 2012; Kiili, 2005; Meluso, Zheng, Spires, & Lester, 2012; Oblinger, 2004; Yien, Hung, Hwang, & Lin, 2011). The learning environment of game-based learning guides students to learn in the virtual gaming world, engendering motivation to learn as they play (Van Eck, 2006). A design mechanism is adopted to develop problem solving skills including creative thinking, reasoning and critical thinking. (Cheng, She, & Annetta, 2015; McFarlane, Sparrowhawk, & Heald, 2002; Papastergiou, 2009). Reasoning is a thinking process that involves deriving new information from old materials, enabling an individual to establish the correlation between systematic principles and premises. Also, reasoning is considered a high order cognitive ability; it is a problem solving ability which assists an individual, through the process of logical reasoning, in gaining a clear understanding of the causal events in the environment where she/he is situated (DeLoache, Miller, & Pierroutsakos, 1998).

In the studies investigating the ways to cultivate reasoning ability, cognitive styles have been considered one of the important factors influencing reasoning ability (Miller, 1987), and the differences between various cognitive styles are reflected in the response of individuals towards information experience and the process of organizing information (Lee, Cheng, Rai, & Depickere, 2005). As a result, the performance behavior and learning effectiveness of learners with different cognitive styles differ, which affects their performance in organizing their learning experiences (Sternberg & Grigorenko, 1997). Some studies emphasize that during the learning process if an adaptive learning environment can be provided and is able to bring learners' cognitive styles into full play, the learning effectiveness among them can be improved (Thomas & McKay, 2010). Riding and Rayner (1998) point out that in deploying learning strategies, if consideration is given to reconcile the differences in the cognitive styles of learners during the design process, it will be possible to identify the learners' learning difficulties as well as to enhance learning effectiveness.

Many studies examining education and digital games point out that a well-designed digital game should be equipped with adaptive game rules and task objectives (Waraich, 2004), and this eventually brings gamers into the storyline of the game, which encourages them to continue to play the game. As reasoning ability and new knowledge acquisition have an intimate relationship, and that learners' cognitive styles are an important factor that affects individual and environmental information as well as the organization of such information in the reasoning process, developing adaptive reasoning games based on the characteristics of different cognitive styles will be conducive to promoting learners' reasoning ability. In investigating the various dimensions of different cognitive styles, Witkin's field dependence-independence (FD-I) is one of the most widely used methods in the teaching field for identifying learners' cognitive styles (Chen & Macredie, 2002; Mampadi, Chen, Ghinea, & Chen, 2011; Witkin, Moore, Goodenough, & Cox, 1977). Therefore, based on the FD-I oriented characteristics, this study constructed an adaptive reasoning game that makes use of various task objectives in each level to allow learners to complete the game tasks by interacting with the learning contents of the game. And further to examine the effectiveness in enhancing reasoning ability by comparing the reasoning ability pre-tests and post-tests.

In addition, a clustering algorithm using the big data analysis method based on the students' behavior in the game activity logs is employed. The learning behavior logs generated by digital learning environments, by means of the big data analysis method, come to provide research investigations that are different from the traditional methods of examining learning effectiveness – and this has become the development trend in recent years (Baker & Yacef, 2009; Mohamad & Tasir, 2013). Collecting game behaviors in a game learning environment and constructing behavioral models using big data analytics can help reveal the correlation between game behavior, game design and learning effectiveness (Hou, 2015; Hou & Li, 2014).

In light of the correlation between game-based learning, cognitive style and reasoning ability, and the importance of big data analytics, this study aims at developing an interactive digital game, through which FD-I learners are able to review the improvement of their reasoning ability following the gaming activities, as well as providing a design mechanism for this type of games. Through introducing this game in the empirical field and gathering the behaviors of individuals interacting with different objects in the game, as well as using the quantitative analysis conducted through the clustering algorithm of big data and the pre-tests and post-tests testing the effectiveness of the reasoning ability, this study seeks to examine the effects of the design strategies and auxiliary mechanisms on learners with FD-I characteristics.

This study carried out an empirical research on the sixth graders of an elementary school in southern Taiwan, and investigated the following research questions:

- With respect to the improvement of reasoning ability, has the reasoning ability of the experimental group significantly improved compared to that of the control group?
- Based on the game design mechanisms used in this study, does the design mechanisms of adaptive reasoning games be able to correspond with the gaming behaviors of FD-I learners?

2. Research Methods

2.1 Adaptive Reasoning Game

The game developed by this study was “Dio’s Wonderland Adventure,” which is a puzzle and adventure game that incorporated reasoning techniques. The protagonist of the game is a little boy called Dio, who has to solve problems and take adventures in a fantasy journey. To play this game, players would engage in dialogues with a non-player character in the game scenes, make use of different reasoning techniques, and through collecting props as well as thinking about how to use those props, solve the layers of puzzles embedded in each level in order to advance. The game has eight independent levels which are sequentially correlated. Players have to overcome the challenge of each level before they can proceed to the next level. In addition, the game emphasizes the relationship between digital games and cognitive styles when designing games.

According to the characteristics of FD-I, the game offered nine FD-I-oriented design strategies, which respectively were (1) text description, (2) prompt ratio, (3) instructional prompts, (4) feedback prompts, (5) prompts for passing a level, tasks and puzzles, (6) types of puzzles, (7) auxiliary prompt objects, (8) level sequence, and (9) strengthened props. While (8) and (9) design mechanisms remain the same for FD and FI, the display of the remaining seven design principles and mechanisms differed in each level. For example, while it is appropriate to provide field-dependent people with a clear and definite teaching strategy with a lot of guided information, field-independent people are able to engage in learning even with less available information. Therefore, in respect of prompts, the game designed by this study provided FD with a gaming process with full dialogues, as well as clear and visible scene objects. By comparison, the FI gaming process is designed to have only a few prompts, with hidden scene objects that required searching.

2.2 Instruments

In order to evaluate the effects of the design of this study on the reasoning ability of students with FD-I cognitive styles, the participants were invited to fill out two scales, the hidden figures test (HFT) and the standard progressive matrices-parallel form (SPM-P).

- Hidden figures test
  This test was developed by Messick and published by the Educational Test Service in the USA (Messick, 1984). Its main purpose is to evaluate whether the subjects’ cognitive styles are skewed towards FI or FD in order to provide a reference for teaching and counseling. The split half reliability of this test was 0.86.
- Reasoning ability test - Standard Progressive Matrices-Parallel Form (SPM-P)
  The main purpose of SPM-P is to evaluate the reasoning ability of the participants. It includes the two cognitive principles which are relationship theory and correlative reasoning. The former stresses induction and analogy, while the latter is linked to deductive ability (Raven, Raven, & Court, 1998). This scale is designed for people between 7 and 18, and hence can be used on participants in this study. The split half reliability of this scale ranged from 0.87 to 0.92 while its internal consistency reliability ranged from 0.83 to 0.90.

2.3 Participants and Learning Activity

The participants of this study were 112 sixth graders from an elementary school in southern Taiwan. 59 students were assigned to the experimental group, and 53 students to the control group. They took part in the HFT prior to the activity to confirm whether their cognitive styles belonged to FI or FD. The experimental group was further divided in the FI and FD groups, with 29 and 30 students respectively. With respect to activity planning, this study arranged for the experimental group to take part in the reasoning game activity after school, while the control group did not participate in any gaming activity other than the standard curriculum of the school. There was a total of 10 gaming activities, with each lasting 35 minutes. Regarding the evaluation of reasoning ability, the participants took the SPM-P both before and after the activities, the results of which were used to evaluate improvement of the participants’ reasoning ability.

2.4 *Data Collection and Analysis*

In order to fully investigate the effects of the interactive reasoning game developed by this study on the reasoning ability of FD-FI students, this study relied mainly on the quantitative data and the behavioral logs collected during the learning activities, and further conduct statistical analysis and cluster analysis to the data. The data mainly came from (1) the reasoning ability tests, and (2) the behavioral logs of the gaming process, which are explained as following.

- Reasoning ability
  The data was collected from the reasoning ability pre-tests and post-tests completed by the participants. A t-test was performed to examine the improvement of reasoning ability among participants in the control group and that of the FD-I students in the experimental group respectively after the adaptive reasoning game activity.
- Behavioral logs of the gaming process activity
  The data was collected from the records of each key action committed by the participants when they were playing the game. To align with the mechanism of the adaptive reasoning game planned and developed by this study, eight key points would be logged by the computer. The eight key points were: (1) prop acquisition, (2) use of props, (3) combine props, (4) successful use of props, (5) successfully combine props, (6) help with prompts, (7) enter a level, and (8) pass a level. These behavioral logs were to serve as the training and testing dataset for performing the clustering algorithm. According to the result of cluster analysis, the purpose in revealing the behavioral tendency of FD-I participants, and further to uncover whether the design mechanisms of adaptive reasoning games are able to correspond with the gaming behaviors of FD-I learners.

3. Results and Discussion

3.1 *Effects of Adaptive Reasoning Game on Improving the Reasoning Ability of FD-I students*

This study hypothesized that after the reasoning activities, the reasoning ability of students participating in the reasoning games would be improved. A t-test was performed on the reasoning ability results of each pre-test and post-test completed by the three groups in order to identify any significant differences among them, as shown in Table 1. The results show that there were significant improvement in the pre-tests and post-tests that evaluated the reasoning ability of the participants during reasoning game activity, while the control group was not significant. In other words, the reasoning game developed by this study is effective in improving the reasoning ability of FD-I participants.

Table 1

T-test of the pre-tests and post-tests of the students participating in activities

	Mean	SD	t value	p value
Control group (N=53)				
Pre-test	94.55	14.21	-1.43	.158
Post-test	96.85	17.26		
FD group (N=30)				
Pre-test	83.57	12.99	-2.53*	.017
Post-test	89.30	16.41		
FI group (N=29)				
Pre-test	102.62	14.49	-2.61*	.014
Post-test	109.38	15.74		

*p<.05

3.2 *Characteristics of the Cluster Analysis via Playing Adaptive Reasoning Game*

Based on the game behavioral logs, there were totally 177 records that were further subjected to cluster analysis. The input factors were the seven attributes derived from the eight key points, and the output factors were the FD-I cognitive styles. Of the 177 records, three quarters of them were used as training dataset, while the rest as testing dataset. In the end, five clusters were obtained as shown in Figure 1. In the status column, the black vertical bars indicate the scope of that cluster data in ascending order; the light blue rhombus height represents the mean and distribution range of the standard deviation of that cluster data; and the red color in cognitive styles (CS) represents FD, while the blue represents FI. Figure 1 shows that there are 46 cases in Cluster 1, of which 79.1% are FI students and 20.9% are FD students. There are 37 cases in Cluster 3, of which only 42.5% are FI students, while 57.5% are FD students. This means that when the dataset is close to Cluster 1, they tend to be identified as students with FI cognitive style.

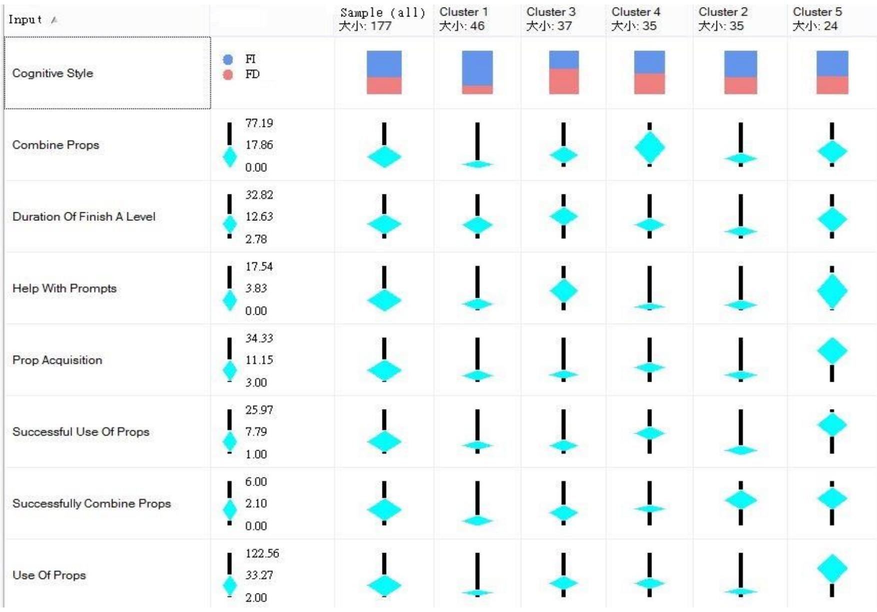

Figure 1. Specification of the characteristics of each cluster in the cognitive style model

Table 2 shows the characteristics of each factor in each cluster. However, how to define to which cluster a dataset belong remains difficult. Only by importing the dataset into the model can the cluster it belongs to be determined. In order to interpret the difference between these two clusters, the cluster identification tool among the SQL Data Tools was used to perform differential analysis so as to present the differences between the factors in Clusters 1 and 3, as shown in Figure 2.

Table 2

Analysis table of the characteristics of the factors of the cluster analysis model

Sample Size	Cluster 1	Cluster 3	Cluster 4	Cluster 2	Cluster 5
	46	37	35	35	24
Cognitive style (FI/FD)	(0.791/0.208)	(0.425/0.575)	(0.516/0.484)	(0.610/0.390)	(0.579/0.421)
Successful use of props (times)	(3.21~7.91)	(2.22~8.78)	(8.58~15.95)	(0.19~5.29)	(10.23~23.96)
Successfully combine props (times)	(0~1.33)	(0.58~2.76)	(1.68~2.71)	(2.05~4.82)	(2.13~5.17)
Use of props (times)	(6.09~20.33)	(21.15~59.30)	(24.80~55.69)	(7.53~26.34)	(36.64~123.99)
Help with prompts (times)	(0.16~4.70)	(2.70~12.59)	(0.06~2.77)	(0.12~3.78)	(0.26~14.72)
Time taken in passing a level (minutes)	(5.83~17.96)	(11.18~24.02)	(7.61~16.48)	(4.40~10.64)	(6.84~24.48)
Combine props (times)	(0~11.12)	(5.35~34.76)	(4.25~63.15)	(5.74~23.41)	(6.22~46.79)
Acquire props (times)	(3.67~11.37)	(5.08~11.43)	(9.31~16.85)	(4.86~10.90)	(14.58~35.53)

The length of the horizontal bars in Figure 2 represents the conditional probability distribution of cluster differences. The greater the probability value is, the longer the length of the horizontal bars is. Conversely, the smaller the probability value is, the shorter the length of the horizontal bars is. Thus, when the dataset moves closer to Cluster 1, it is more likely that the participants have the FI cognitive style; conversely, when the dataset moves closer to Cluster 3, it is more likely that the participant have the FD cognitive style.

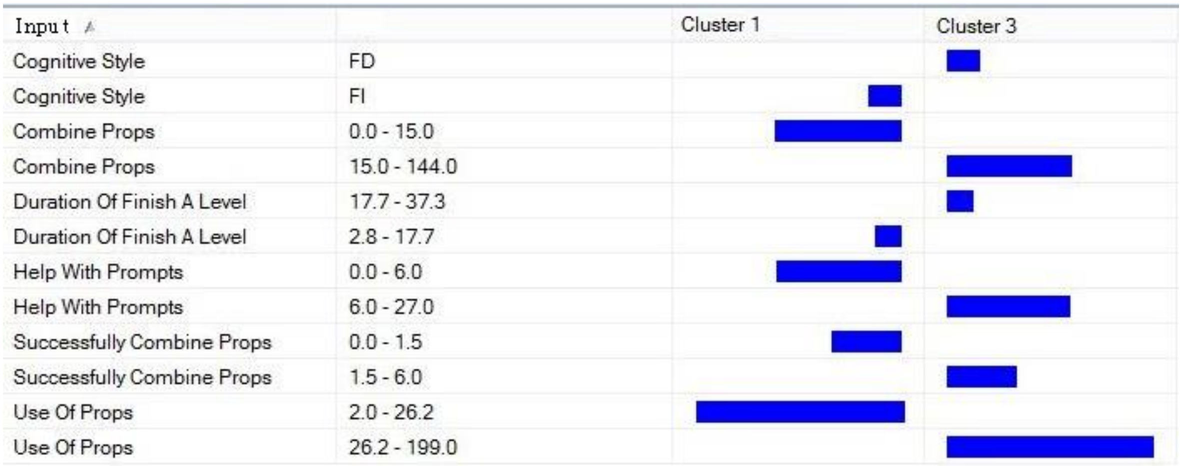

Figure 2. Differential Analysis of Custer 1 and Cluster 3

4. Conclusions and Recommendations for the Future

The results of this study can be served as a reference for designing digital reasoning games for learners with different FD-I characteristics. At the same time, valuable recommendations from this study will be useful for subsequent research. First, the sample size of the current research subjects is small, and the study largely focused on senior elementary school students. It is therefore recommended that subsequent research increase the sample size and extend the subjects to the elementary students of other grades. In this way, future research will be able to provide more evidence for verifying the deviant behaviors of these seven FD-I game design mechanisms, and provide clearer functional designs and auxiliary mechanisms for planning reasoning games.

Acknowledgements

The authors would like to thank the Ministry of Science and Technology in Taiwan for financially supporting: MOST 106-2511-S-147-001, and MOST 105-2511-S-024-006-MY3.

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