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The Impact of Game Playing on Students' Reasoning Ability, Varying According to Their Cognitive Style

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ABSTRACT: Students with different cognitive styles benefit from different instructional strategies, including learning through playing video games. Although playing video games can be an effective learning method, we do not know its impact on the reasoning ability of students with different cognitive styles. The purposes of this study are to investigate whether students with different cognitive styles improve their reasoning ability after playing video games and whether the effect is the same for all students. We used a pretest-posttest experimental design with multivariant analyses and found that elementary school students' reasoning ability improved reliably after playing a puzzle adventure game for four weeks, twice a week. In addition, field-independent students' reasoning ability improved reliably more than field-dependent students did. Students with different cognitive styles also demonstrated noticeably different information search strategies during game playing. Our work answers the questions regarding the impact of playing video games in students' reasoning ability and in students with different cognitive styles. We also suggested guidelines of designing educational video games for field-dependent and field-independent students. Future studies are needed to expand our understanding to the relationships between other types of video game, cognitive ability, and cognitive styles.

Keywords: Cognitive style, Digital game, Reasoning ability, Game-based learning

1. Introduction

Reasoning is a critical thinking skill that people frequently use in daily life. To solve problems, people need the reasoning ability to generate rules from a complex reality, to evaluate and judge relations from external information, and eventually, to produce a solution. While some studies showed that abstract thinking, the use of related knowledge, and inductive and deductive reasoning are important factors in enhancing student's learning process (Kline, 1994; Leighton & Sternberg, 2004; Nickerson, 1991), others had attempted to better understand individual differences in the human reasoning process (Carroll, 1993; Lohman & Lakin, 2011; Sternberg, 1986). Typically, the development of reasoning ability is associated with individuals' metacognition, interpersonal communication, and developmental growth. Having the ability to reason is a part of an individual's ability to performing mental operation, which can be affected by external learning styles and internal cognitive styles. A cognitive style describes how an individual perceives, remembers, thinks, and solves problems in different contexts (Lomberg, Kollmann, & Stöckmann, 2017; Volkova & Rusalov, 2016) and it varies by person. Therefore, cultivating reasoning ability has to account for cognitive styles. Learners with different cognitive styles may need different learning strategies and processes to facilitate effective learning.

Riding and Sadler-Smith (1997) pointed out that learning strategies designed specifically for individuals with different cognitive styles have a better chance of increasing the efficiency and effectiveness of learning and assisting learners with overcome learning difficulties. It is important to include cognitive styles when one studies pedagogical strategies. Otherwise, some strategies that favor one group could result in no effect for the other. To use digital games for learning effectively, it is important to examine whether and how playing digital games affect students with different cognitive styles. Research has shown that students with different cognitive styles demonstrate different preferences in learning and social adaptation (Chen & Chang, 2016). The authors found that if students have a cognitive style that is similar to that of their teacher, they have a higher chance of reporting a more positive learning experience. This study shows that the effect of learning for students with different cognitive styles varies.

Recent research in learning technology attempted to exploit digital games to help students learn reasoning and problem-solving skills. Young children play games to build their self-esteem and self-efficacy, to acquire metacognition and motor skills, to practice interpersonal and social communication, to improve developmental growth, to participate in role play, and to exercise emotional expression (Broadhead, 2006; Erhel & Jamet, 2013; Kennewell & Morgan, 2006; Li & Tsai, 2013; Moreno, 2012). These studies showed that playing digital games could be more than solely for entertainment; it can also be an effective approach to cultivate children's reasoning ability. Salient issues such as relationships among digital games, reasoning ability, and cognitive style, however, remain unaddressed, leaving ample opportunities for further investigations.

This study aims to investigate whether a child's reasoning ability can be facilitated in a digital adventure gaming environment and whether cognitive styles—field-independent (FI) vs. field-dependent (FD)—affect the acquisition of reasoning ability in the gaming environment. In short, FI and FD are distinguished by the ability to discern detail information from its surrounding environment, where people with FD style being relatively weaker than those with FI. Detailed descriptions of these two cognitive styles are provided in the next section (Literature Review). We expect to see a positive learning experience of using digital games in promoting children's reasoning ability. Additionally, we expect that their cognitive styles will affect the outcome of using digital games to facilitate the acquisition of reasoning ability. Four research questions were studied as follows:

- Does a child's achievement score on a pretest and a posttest show significant differences after experiencing digital game playing?
- Does the achievement score of children with different cognitive styles differ after experiencing digital game training and paper-based training?
- Does a child's pattern of game playing show reliable difference according to their cognitive style?
- Will a FI child tend to think more independently and not require much external assistance than a FD child?

2. Literature review

It is known to researchers that field-dependent and field-independent learners prefer different instructional models and materials. It is not clear how these learners would behave in and learn from playing video games. The correlation between video game playing and reasoning ability is also unclear. In this section, we review some key concepts and recent studies related to reasoning ability, video games, and cognitive styles.

2.1. Reasoning ability and its development

Reasoning ability normally described as one of higher-order thinking skills (Krulik & Rudnick, 1993) and is an essential ability when dealing with real-world problems. It allows an individual to use prior knowledge with new information and apply principles systematically to construct the relation between old and new problems (Rosser, 1994; Spitz, 1979). This mental process enables a person to make logical arguments (Barbey & Barsalou, 2009) apply logical rules (Wilhelm, 2005) and understand casual relations in an environment (Piaget & Inhelder, 2008). Because learning cannot possibly cover all known situations, reasoning ability becomes especially crucial for preparing an individual for future unknown problems. We regard reasoning ability as an individual's ability to deliberately use known information to solve an unseen problem.

The development of cognitive skills is a gradual process, from simple and concrete to complex and abstract. The participants in the study were 6th graders who, according to Piaget's stages of cognitive development, were between the late concrete operational stage and the early formal operational stage. In the concrete optional stage, students tend to have logical reasoning thinking of concrete issues and concepts of classification and sequence. In the formal operational stage, students develop the ability to think about abstract concepts and are able to think logically—a systematic and logical process (Piaget & Inhelder, 2008). This is a crucial period when students transition from concrete to abstract reasoning; therefore, they should be provided with appropriate teaching aids. Further, developmental training is important for students during this period. Various challenges and puzzles in a digital adventure game were used to train the participants of this study. In general, three reasoning methods—deductive reasoning, inductive reasoning, and analogical reasoning—are used in problem solving. Deductive reasoning is used to verify hypotheses, inductive reasoning is used to formulate general rules, and analogical reasoning is used to apply general rules to similar situations. In this study, participants needed to use available information from the game scenarios, combine it with prior knowledge as the basis to perform deductive, inductive, or analogical reasoning to identify and solve problems by manipulating rules—a reasoning process (Wilhelm, 2005). We believe it is plausible to use digital adventure games to cultivate reasoning ability.

2.2. Reasoning ability and digital games

Previous research studied the effects of digital games on reasoning ability and found that these games could be used effectively to enhance children's reasoning abilities (Bakker et al., 2015; Bottino et al., 2007; Liu & Lin, 2009). Because problem solving abilities intertwine with reasoning abilities, we included studies about digital games and problem solving in this section as well.

Mather (1986) reported that adventure games could improve students' reading skills, cultivate their creativity, and enhance their problem-solving ability. Australian researchers conducted a study on elementary students to find whether playing adventure games helped students' learning, and the results showed that these games could in fact improve students' problem-solving ability and skills (Grundy, 1991). Dempsey, Lucassen, Haynes, and Casey (1996) conducted a study on 40 adults with regards to adventure games and learning. Their results illustrated that these games were beneficial for problem-solving and decision-making abilities. In addition, Amory, Naicker, Vincent, and Adams (1998) conducted a study on 20 college underclassmen in England to find the most applicable educational digital games and interesting or helpful game elements. The results showed that adventure games could combine pictures, sounds, and stories to improve students' logic, memory, imagination, and problem-solving ability. Hsiao et al. (2014) discussed how adventure games affected 5th graders' creativity, problem-solving ability and achievement motivation. The results indicated that the experimental group had higher scores on the posttest of the problem-solving assessment than the control group did. These studies suggested that playing adventure games could develop general problem-solving abilities.

The results of the previous mentioned studies indicated that digital games positively affected problem-solving and that reasoning ability was associated with problem solving. Reasoning abilities and problem-solving abilities are often considered complementary to each other (Jenny & Claire, 2008; Krulik & Rudnick, 1993). Reasoning out the answer requires a student to examine if the solution is logical and plausible. Aside from chance or luck, students must know how and where to find the solution to a problem. Puzzle games emphasize on solving problems and often require the players to use reasoning ability with given information and available objects in a novel situation. Therefore, puzzle adventure games should have positive effects on problem solving, and the study focused on whether puzzle adventure puzzle games affected reasoning ability positively (Bakker et al., 2015; Crompton et al., 2018). Players' acceptance and adaptability of digital games vary slightly due to different cognitive styles, methods of processing information, individual cognitive capacity, thinking ability, and abilities to generalize symbols (Lin et al., 2011). In this study, we analyzed how playing a puzzle adventure game affected players' reasoning ability and discuss how players with different cognitive styles approach problems and obstacles when playing this puzzle adventure game.

Digital adventure games are video games that players control characters to interact with objects or other computer-generated characters to solve problems or puzzles in an artificially created digital world (Cavallari, Hedberg, & Harper, 1992). They normally contain adventure stories with rich context. In such a simulated world, players can try many actions, such as opening a door, throwing a rock, combining two objects to solve different problems or challenges. They often need to decode messages, make hypotheses, or apply inferences in their journey of the story (Chandler & Chandler, 2011). Regarding the benefit of playing digital adventure games, Ju and Wagner stated that reasoning and problem-solving skills are required in adventure games (Ju & Wagner, 1997).

2.3. Cognitive styles

Researchers have attempted to measure different cognitive styles and identify characteristics of different dimensions of cognitive style so that they could better understand human mental operation. Messick (1984) proposed approximately 20 cognitive styles and there were over 30 cognitive styles proposed (Riding & Cheema, 1991). Nevertheless, some of them were repetitive or excessively overlapping with one another. Riding and Cheema (1991) proposed two main orthogonal cognitive style families, "wholistic-analytic" and "verbal-imagery", based on their review of cognitive style. Previous studies on teaching and learning mainly focused on analyzing learning achievement and attitude with regard to field-dependent (FD) and field-independent (FI) (Sadler-Smith, 2001; Riding & Rayner, 2013). Because "FD vs. FI" was studied most widely and many assessment tools for learner's performance in digital games have been validated, we adapted the "FI vs. FD" paradigm in this study.

Based on their research results, Witkin, Moore, Goodenough, and Cox (1977) identified that there are various differences between FD and FI people. FI people had a tendency to be more autonomous in relation to the development of cognitive skills and less autonomous in relation to the development on interpersonal skills;

conversely, FD people had a tendency to be more autonomous in relation to the development of high interpersonal skills and less autonomous in relation to the development of cognitive restructuring skills. In addition, FI people preferred individualized learning whereas FD ones enjoyed cooperative learning. Studies (Chen & Chang, 2016; Lomberg et al., 2017; Lugli et al., 2017) indicated that FD students tended to emphasize a certain aspect and searched for solutions based on certain casual relations or reasons. These students also tended to rely on external cues to observe subjects, make a judgment, and needed constructed materials to learn knowledge. FI students, on the other hand, tended to organize learning materials based on the understood casual relations and analyses of reasons. Although their cognitive styles were different, FD and FI students' intelligence and intellectual level were not directly correlated. Students with different cognitive styles might have the same intelligence or intellectual level (Tamaoka, 1985). They simply thrived under different learning conditions. Two studies showed that different cognitive styles affected students' learning behaviors, and those with FD and FI appeared to have different academic performances due to pedagogical strategy (Chang, Lin, & Chen, 2019; Chen & Macredie, 2002). Researchers suggested that teacher must adapt their instruction to students with different cognitive styles and provide necessary assistance to achieve a better learning outcome (Mefoh et al., 2017; Thomas & McKay, 2010).

Researchers developed Embedded Figures Test (EFT) to categorize an individual as FD or FI. According to the EFT, those who tend to rely on external cues and are less able to differentiate an embedded figure from an organized field are labeled as FD while those who tend to rely on internal reasoning and are better at differentiating an embedded figure from an organized filed are labeled as FI. Therefore, FI people are able to analyze a larger complex figure, distinguish discontinuous parts from the figure by ignoring irrelevant information, and extract the embedded figures, and coordinate the embedded figures as obligatory in the organized field; FD people tend to view the organized field as a whole and thus are unable to eliminate unrelated parts of the complex figure. Therefore, how students with FD or FI perform in a puzzle adventure game with rich pictures and different information is worthy of investigation.

Parkinson and Redmond (2002) investigated the relations among cognitive styles, learning outcomes, and three different types of learning media: texts, multimedia CD-ROM, and the Internet. Lee et al. (2005) explored the relations between cognitive styles and learning preferences in a fundamental multimedia course of the hypermedia learning system. Mampadi, Chen, Ghinea, and Chen (2011) discussed the differences of the students with FD and FI cognitive styles in the linear and non-linear learning during the digital game play. However, these studies did not analyze the design and content of the digital game.

Other studies showed that different cognitive styles affected students' learning behaviors, and those with FD and FI cognitive styles had different academic performances (Chen & Macredie, 2002; Salih & Erdat, 2007). Teachers needed to adapt their teaching instruction to students with different cognitive styles and learning methods and provide necessary assistance to achieve a better learning outcome (Chen & Macredie, 2002; Hansen, 1997; Riding & Sadler-Smith, 1997).

3. Research method and procedure

To study the effect of playing video games on reasoning ability and whether students with different cognitive styles benefit from playing puzzle adventure games equally, we designed our experimental study with three groups. One group played a puzzle adventure game, one group was trained by solving reasoning problems on papers, and one group did not receive any treatment. In this study, participants in group one needed to use available information from the game scenarios, combine it with prior knowledge as the basis to do deductive, inductive, or analogical reasoning identify and solve problems by manipulating rules to, which in essence is a reasoning process (Wilhelm, 2005). We believe playing puzzle adventure games has the potential of cultivating reasoning ability. We detail our study procedure this section.

3.1. Intervention instruments

The digital game group (T1) played a puzzle adventure game called Machinarium (Figure 1) in the experiment. In this game, players control a character by using a mouse to point-and-click to solve a series of puzzles and brain teasers that require reasoning ability. The game contains no human language conversation, so players have to rely on observing objects on the scene, making inference of their relations, and connecting related ones to help them solve the puzzles. The game includes five levels. There are several challenges in each level and several puzzles in each challenge in the game. To solve the puzzles, players must apply problem-solving skills, which cultivates reasoning ability and promotes higher order thinking skills. While participants were playing the game, their mouse clicks and movements were recorded using a program called Morae Recorder. The recorded logs allow us to analyze players' behavior patterns.

Figure 1. A snapshot of the puzzle adventure game cover

Another group of participants received a paper-based training (T2) with the same amount of time and frequency as participants in T1. The training is based on a book that trains logic thinking and reasoning for children around age 12 or above. The training on the paper is text-based descriptions and activities. The no-treatment group (T3) received neither the video game nor the paper-based training during that time.

3.2. Assessment of reasoning abilities

Raven (1936) developed the Ravens's Progressive Matrices (RPM) to measure the reasoning component of Spearman's g, which consists of the two principles in cognition, education of relations (i.e., induction and analog ability) and education of correlations (i.e., interpretation ability). Standard Progressive Matrices (SPM) was the original version of the family of the matrices. Other matrices such as the Colored Progressive Matrices Parallel (CPM-P), the Standard Progressive Matrices Parallel (SPM-P), and the Standard Progressive Matrices Plus (SPM^{+}) were published after SPM. We chose SPM-P because it is designed for children of age between 10 to 12 and it has high reliability. The SPM-P consists of 60 items that are evenly divided into five series. Each item consists of an incomplete pattern (matrix) that the subject is to find the matching piece out of six choices shown beneath the matrix. The internal consistency reliability of the SPM-P is between 0.83 to 0.90; the split-half reliability is between 0.87 to 0.92; the test-retest reliability of the five-week study is 0.81.

3.3. Experimental procedure

The participants of this study were 140 6^{th} graders at an elementary school in Southern Taiwan. They were randomly assigned into three groups, treatment group 1 (T1), treatment group 2 (T2), and a control group (T3), based on the scores of a cognitive style inventory called Hidden Figure Test (HFT). According to the HFT test score, participants were divided into three groups: FI, FD, and indeterminate. In the FI group, participants were randomly assigned to T1, T2, and T3. The same assignment was done for the FD group. Finally, the participants in the indeterminate group were randomly assigned to T3. The diagram in Figure 2 shows the details of our experimental procedure. The participants whose scores on the HFT are higher than the mean of the highest score and the lowest score are categorized as FI participants. Those whose scores on the HFT lower than the mean of the highest score and the lowest score are categorized as FD participants. Some participants were moved to the control group in order to afford each participant a personal computer in T1 and to balance the number of FI and FD participants in T1 and T2. Table 1 shows the final number of participants in each group.

The participants received a pretest prior to the experiment and a posttest after the experiment. Those in the T1 played the puzzle adventure game for eight times in four weeks, each lasted 35 minutes. Students in the T2 received paper-based training for eight times, again, each lasted 35 minutes. The T3 was regarded as the control group, which received no training activities in this study.

Table 1. Distribution of participants

Participants	T1 (Puzzle Adventure Game)	T2 (Paper-based Training)	T3 (Control)
FD	16	15	51
FI	14	14	30
Total	30	29	81

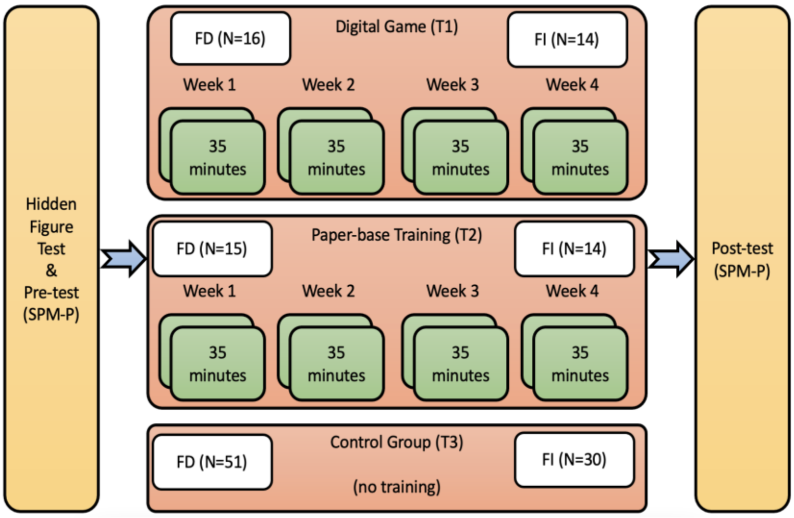


Figure 2. Experimental procedure diagram

3.4. Research design

The research design in the study was a randomized pretest-posttest with a control group design. The two independent variables were game playing and paper-based training. The dependent variables were the SPM-P criterion tests that were given immediately after the participants finished the treatment.

A Multivariate Analysis of Variance (MANOVA) was used to analyze data. The main effects and the potential interaction of the two independent variables were examined. Where significant *F*-values were found, pair-wise multiple comparison tests were performed using the Scheffe test.

4. Findings

4.1. Results of multivariate analysis of variance (MANOVA)

This research design of the study is a randomized 2 x 3 pretest and posttest design. The two independent variables are: cognitive styles (FD and FI) and treatment types (T1: puzzle adventure game; T2: paper-based training; T3: no training). The dependent variable was students' reasoning ability measured by the Standard Progressive Matrices Parallel (SPM-P). A multivariate analysis of variance (MANOVA) was conducted to analyze the collected data from 140 participants.

A descriptive statistics summary including both pretest and posttest is illustrated in Table 2.

Table 2. Means and standard deviations of the SPM-P measurement

Test	FI						FD					
	T1 (*n* =16)		T2 (*n* =15)		T3 (*n* = 50)		T1 (*n* = 14)		T2 (*n* = 14)		T3 (*n* = 31)	
	M	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*	*M*	*SD*
Pretest	106.57	14.92	94.07	17.84	96.25	17.19	104.50	13.92	104.54	16.50	95.22	15.49
Posttest	118.07	10.24	103.87	12.99	99.83	18.38	108.23	15.68	104.00	18.49	96.45	16.68

The results from the MANOVA (shown in Table 3) indicated that the two independent variables (cognitive style vs. training) had no statistically significant interaction (for the pretest, $F = .15$; $p = .864$; for the posttest, $F = .75$; $p = .477$). Therefore, it is valid to analyze the effects of cognitive styles and gaming on student's reasoning ability independently.

Table 3. MANOVA analysis of between-subjects effects

Source	Dependent Variables	df	SS	MS	F	p
Cognitive Styles	Pretest	1	2575.27	2575.27	10.55	.001*
	Posttest	1	2588.30	2588.30	10.25	.002*
Experimental Groups	Pretest	2	7.82	3.91	.02	.984
	Posttest	2	1718.11	859.05	3.40	.036*
Cognitive Styles ×	Pretest	2	72.25	36.13	.15	.864
Experimental Groups	Posttest	2	376.638	188.32	.75	.477
Error	Pretest	129	31477.97	244.02		
	Posttest	129	32590.32	252.64		
Total	Pretest	135	1366422.00			
	Posttest	135	1475671.00			

Note. $^{*}p < .05$.

Table 2 and Table 3 also showed that regardless of experimental treatments, FI students performed reliably better than the FD students in both pretest ($F = 10.55$, $p = .001$) and posttest ($F = 10.25$, $p = .002$). Among the experimental groups, a significant difference was found in students' posttest ($F = 3.40$, $p = .036$). A follow-up Scheffe multiple comparison test was conducted to discern the significant difference (illustrated in Table 4). We found that the difference came from the gaming group and the control group ($p = .018$).

Table 4. Scheffe multiple comparison of groups

Source		Mean difference	Std. Err.	Significance
Pretest	T1 & T2	-.456	4.263	.994
	T1 & T3	1.449	3.380	.912
	T2 & T3	1.905	3.573	.868
Posttest	T1 & T2	8.724	4.337	.137
	T1 & T3	9.909*	3.439	.018*
	T2 & T3	1.185	3.636	.948

Note. $^{*}p < .05$.

4.2. Results of univariate analysis of variance (ANOVA)

According to Table 5, a significant difference was found in the posttest between FI and FD students ($F = 10.59$, $p = .003$) in T1 (gaming). By considering the results in Table 2, we found that FI students (mean = 118.07; standard deviation = 10.24) obtained a significant better reasoning ability than the FD students (mean = 103.87; standard deviation = 12.99) in the gaming group.

Table 5. ANOVA analysis of posttest for Treatment 1

Source	Dependent variables	DF	SS	MS	F	p
Pretest	Between groups	1	1132.39	1132.39	4.16	.051
	Within groups	27	7348.36	272.162		
	Total	28	8489.69			
Posttest	Between groups	1	1461.13	1461.13	10.59	.003*
	Within groups	27	3724.66	137.95		
	Total	28	5185.79			

Note. $^{*}p < .05$.

In T2 (paper-based training), no significant difference was found in both pretest ($F = 1.513$, $p = .231$), and posttest ($F = 0.319$, p = .578) between FI and FD students, according to Table 6.

Table 6. ANOVA analysis of posttest for Treatment 2

Source	Dependent variables	DF	SS	MS	*F*	*p*
Pretest	Between groups	1	428.68	428.68	1.513	.231
	Within groups	23	6517.48	283.369		
	Total	24	6946.16			
Posttest	Between groups	1	108.33	108.33	.319	.578
	Within groups	23	7821.67	340.07		
	Total	24	7930.00			

Note. $^{*}p < .05$.

In T3 (control), significant differences were found in both pretest (F = 7.30, p = .008) and posttest (F = 9.84, p = .002) between FI and FD students. By considering the results in Table 7, we found that in the control group, FI students performed reliably better in reasoning ability test than the FD students in both pretest and posttest.

Table 7. ANOVA analysis of posttest for Treatment 3

Source	Dependent variables	DF	SS	MS	*F*	*p*
Pretest	Between groups	1	1628.19	1628.19	7.30	$.008^{*}$
	Within groups	79	17612.18	222.94		
	Total	80	19240.32			
Posttest	Between groups	1	2622.29	2622.29	9.84	$.002^{*}$
	Within groups	79	21043.99	266.38		
	Total	80	23666.22			

Note. $^{*}p < .05$.

4.3. Pattern of mouse clicks

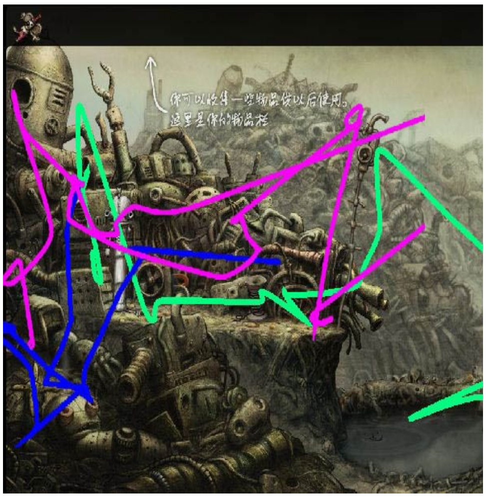
We used Morae Manage to analyze the recordings of the participants' game playing behavior and used the mouse clicks search options to search for all mouse clicks that occurred during a particular time span (i.e., 10 seconds). Figure 3 shows the mouse movements of participants with two cognitive styles in 10 seconds while solving two challenges of level one. The left column illustrates the FI participants' mouse movements while the right column illustrates the FD participants' mouse movements. Players have to search for a doll in the first challenge. As Figure 3 has shown, the traces for FI participants (Figure 3(a)) are more condensed than those on the right (Figure 3(b)). This suggests that the FI participants carefully observed the details around the robot, and the FD participants moved the mouse pointer all around the screen to search for the doll. Similar patterns are observed in another challenge of level one, which are shown at the bottom row of Figure 3.

Because there is a short movie that serves as a hint about the goals of upcoming challenge only in the beginning of level one and level two, we also provide an example pattern from level three when the short movie was not shown to the participants. As suggested in Figure 4, the FI carefully observed the details of the screen. On the other hand, the FD participants moved their mouse pointer all around the screen and clicked the mouse button many times. The pattern is similar to what Figure 3 shows. It illustrates that the FI participants tended to think and analyze the relations and that the FD participants were weaker in reasoning and analytical skills, with or without hints.

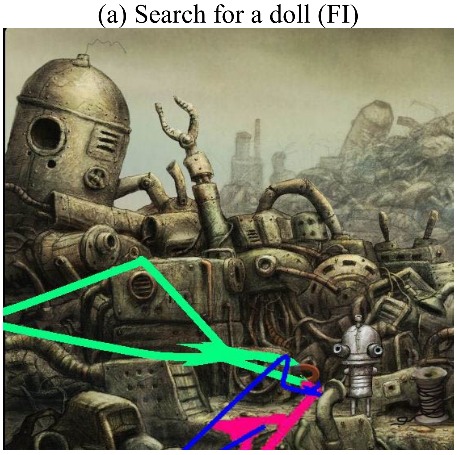
The number of times that FI and FD participants clicked a mouse button in three challenges (1st, 2nd, and 5th) of level three is illustrated in Figure 5. The blue diamonds represent data points for the FI participants, and the red diamonds represent data points for the FD participants.

The results show that the FD participants used much more mouse clicks than the FI participants. A possible explanation is that FI participants tended to think and analyze problems while playing puzzle adventure games and clicking the mouse button was not intentional. However, the FD participants might not carefully analyze the tasks to be completed, which caused quite a few unnecessary random clicks.

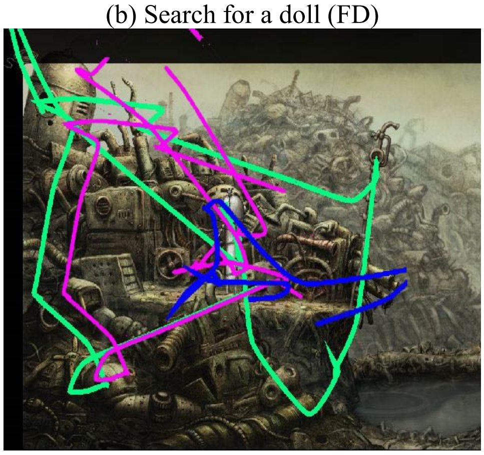
(a) Search for a doll (FI)



(b) Search for a doll (FD)



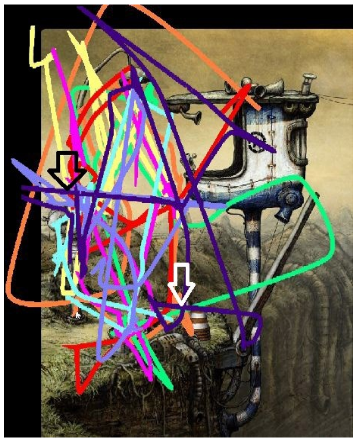
(c) Search for a magnet and a line (FI)



(d) Search for a magnet and a line (FD)

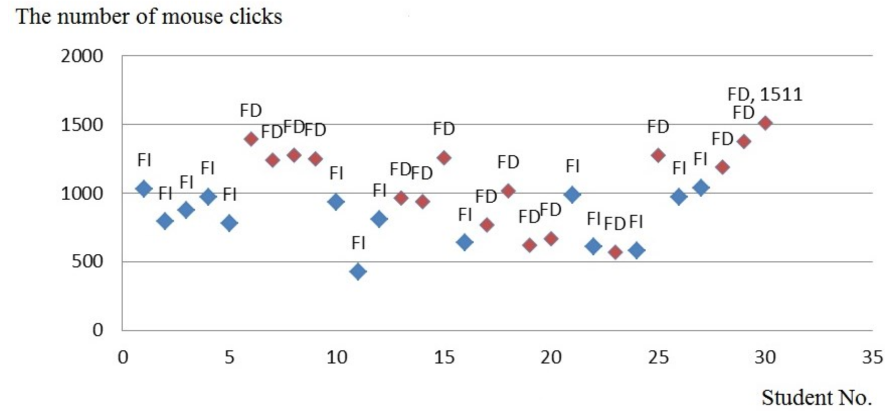
Figure 3. Examples of traces of mouse movements from FI and FD participants in two challenges of level one

(a) Light up the lamp (FI)

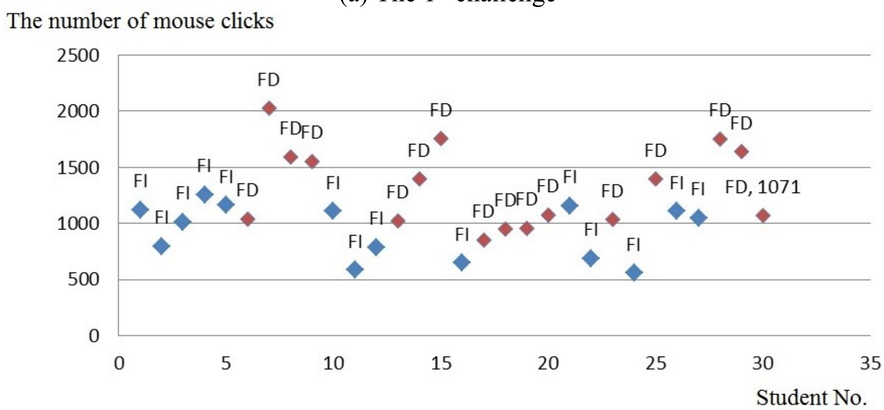


(b) Light up the lamp (FD)

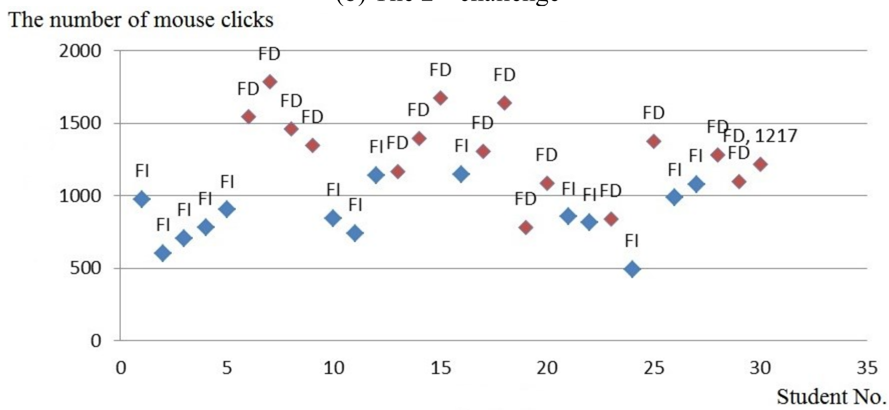
Figure 4. Examples of traces of mouse movements for FI and FD participants on level three



(a) The 1st challenge



(b) The 2nd challenge



(c) The 5th challenge

Figure 5. Numbers of mouse clicks on level three

5. Discussion

From the results, we see that playing the puzzle adventure game improves students' reasoning ability. Further looking at the behavior patterns suggests that students with different cognitive styles use different information seeking strategies. We discuss our results in detail below along with suggestions for further research.

5.1. Effects of puzzle adventure games on reasoning ability

For research question one, does a child's achievement score on a pretest and a posttest show significant differences after experiencing puzzle adventure game playing, we found that participants' score did increase reliably after playing the puzzle adventure game. According to SPM-P scores, there are significant differences in student's reasoning ability among three groups—puzzle adventure game, paper-based training, and no training (control group). Regardless of student's cognitive style, the puzzle adventure game group perform better than those in the control group on the posttest. This finding is consistent with Liu and Lin's results (2009) that indicated playing digital puzzle games improved the players' reasoning ability. The items of SPM-P are non-verbal, multiple-choice questions that test takers must identify the missing elements from a given pattern. Similarly, the puzzle adventure game requires players to solve a series of puzzles using their reasoning ability with no verbal information. Because both the SPM-P test and the puzzle adventure game require the participants to observe the given clues and the surrounding details to solve puzzles using their reasoning ability, it is not surprise that the puzzle adventure game group outperform other groups.

On the other hand, there is no significant difference on the posttest between the paper-based training group and the control group. A possible explanation is that the paper-based training activities require the participants to read, understand, and analyze verbal information to find out the answers. This type of training may be beneficial for verbal reasoning but not for graphical reasoning. As mentioned previously, SPM-P may favor non-verbal reasoning ability, which may not benefit verbal training such as what we did in the paper-based training group. Another reason could be the lack of motivation to learn and to solve the problems. This verbal type of reasoning that paper-based training provides may not attract the participants' attention to solve problems.

With regard to research question two, does the achievement score of children with different cognitive styles differ after experiencing puzzle adventure game training and paper-based training, an interaction between cognitive styles and puzzle adventure gaming effects is also identified. Within the puzzle adventure game group (T1), the FI participants had a reliably higher posttest scores than the FD participants ($F = 10.59$, $p = .003$). This means that after the treatment, regardless of training types, FI learners perform reliably better than FD learners in the posttest measurement. This finding is consistent with previous work that studied cognitive styles and student learning outcome. Based on their research results, Witkin et al. (1977) indicated that FD and FI people have great differences in several ways. For example, FI people have a tendency to be more autonomous in relation to the development of cognitive restructuring skills and less autonomous in relation to the development on interpersonal skills; conversely, FD people have a tendency to be more autonomous in relation to the development of high interpersonal skills and less autonomous in relation to the development of cognitive restructuring skills. In addition, the FI people enjoy individualized learning while the FD ones enjoy cooperative learning. For the paper-based training group (T2), we did not find reliable differences between FI and FD in posttest after treatment. This indicates that there is no difference in posttest between FI and FD in using paper-based training.

5.2. Effects of cognitive styles on reasoning ability

The analysis of the traces of mouse movements, which answers research question three (does a child's pattern of puzzle adventure game playing show reliable difference according to their cognitive style?), indicates that the FI participants tend to observe surrounding details, to search for appropriate prompts from a small to a large area gradually, and to consider possible solutions when solving problems. We believe that they demonstrate independent thinking and that they tend to apply analytical skills without relying on a lot of clues. On the other hand, the FD participants tend to search for appropriate prompts from a large to a small area and think less carefully about solutions. They tend to rely on the given clues in a form of a thought bubble and external assistance from the teacher or the other participants.

Table 8. Differences between FI and FD participants

ID	FI Participants	FD Participants
D1	Carefully thinking before taking actions	Expecting to have more external information
D2	Paying less attention to text descriptions	Paying more attention to text descriptions
D3	Detailed observation of the field	Extensively observing of the field
D4	Less clicking on text descriptions	Often clicking on text descriptions
D5	Taking longer time to combine prompts because of paying less attention to text explanations	Taking shorter time to combine prompts because of paying more attention to text explanations
D6	Considering when and where to use new prompts when receiving them	Storing new prompts until encountering difficulties
D7	Less interaction and discussion with others	More interaction and discussion with others

In addition, the analysis of the numbers of mouse clicks, which answers research question four (will a FI child tend to think more independently and not require much external assistance than a FD child?), indicates that the FI participants tend to independently think before taking actions whereas the FD participants tend to rely on external assistance to solve the puzzles or attempted to ask for useful information. This result is consistent with previous findings from the review of literature, which indicated that the FI individuals generally were analytical in their approach to solve problems, whereas the FD individuals were more global in their approaches and tended to rely on external assistance to solve problems (Mampadi et al., 2011; Salih & Erdat, 2007). Table 8 summarizes our observations about the differences of the FI and FD participants while playing the puzzle adventure game.

Kozhevnikov (2007) found that the FI students tended to concentrate on a certain aspect and searched for solutions based on certain casual relations or reasons. FD students usually relied on external cues when observing subjects and making judgments, and they needed more help for scaffolding. The FI students tended to organize learning materials based on the known casual relations and on analyses of reasons. Students' intelligence and intellectual level were not directly correlated to either FI or FD.

While playing the puzzle adventure game, the FD learners tend to process information from a global perspective; they are relatively unable to construct their knowledge under a non-structured environment, so they tend to learn passively and rely on external assistance from teachers or classmates. This conclusion is supported by our observation that FD participants tend to click on more prompts than the FI participants did. However, it seems the text descriptions in the prompts of the puzzle adventure game are not sufficient to support the FD participants to solve designated tasks. The future design for the puzzle adventure game could revise its prompt system by considering participants with different cognitive styles or it can be adaptive. For example, the information that the player receives can change based on the number of times the prompt is clicked. To discourage abusing the prompt feature, the points received could decrease as the degree of details increases.

Unlike the FD players, the FI players in the study are analytical and able to construct their knowledge independently so that they do not need the prompt system as much. The linear storyline of the puzzle adventure games may be appropriate for the FI individuals. Non-linear storyline of the puzzle adventure game may be better for the FD players because it did not require players to finish the current level to advance to the next level. The FD players need more text description in the prompts than the FI players to complete a level. On the other hand, FI individuals need more figural questions to improve their reasoning ability.

5.3. Suggestions for further research and puzzle adventure game design

From our observations and analyses, FD and FI participants illustrate some distinct behaviors and preferences (summarized in Table 8). Accordingly, we propose some suggestions for designers of puzzle adventure games to target players of different cognitive styles (see Table 9). Puzzle adventure games could offer them as options to the players and allow them to select the ones they prefer (without preferring the options to FI or FD). This approach could potentially maximize the learning benefit and enjoyment. Because there are endless possibilities for the develop the storylines of a puzzle adventure game, these guidelines are intended for the interactivity and interface design and not for the game content. The labels in the first column (reasons) correspond to the differences in Table 8. The second and third columns describe our suggestions for each type of players.

Table 9. Design suggestions for FI and FD players based on the differences in Table 8

Reasons	FI Players	FD Players
D1, D5	Fewer prompts that contain simple texts	More prompts in a level The more times to click on prompts, fewer points players receive when completing a level
D1, D2, D5	Fewer text descriptions in a level	More text descriptions in a level
D1, D2, D5	More figural questions for reasoning and thinking	More text descriptions of missions
D2, D5	Basic text descriptions of prompts	More text descriptions of prompts
D3	Linear storyline of the puzzle adventure game that requires players to finish the current level and then proceed to the next level	Non-linear storyline of the puzzle adventure game that doesn't require players to finish the current level to proceed to the next level
D3, D4, D6	No hidden prompts	Provide hidden prompts to facilitate players to complete the level

Table 9 provides guidelines for future puzzle adventure game design for FI and FD players. In this table, we list suggestions based on our observation on the differences (illustrated in Table 8) between FI and FD players. According to our findings, future research should continue to investigate the impact of digital gaming environments on students' learning achievement, especially on their higher-order reasoning ability such as problem-solving and critical-thinking skills. In addition, future studies should continue to investigate other human factors in a digital gaming environment such as learners' individual differences, learning styles, and preferences in using visual/audio materials. Many of the independent variables associated with the study of aptitude-treatment interactions should be taken into account in the design of digital gaming environment.

While digital gaming environment may be manipulated to positively influence students' reasoning ability, special attention must be given to concrete game design guidelines derived from reliable experimental methodologies, as well as to consideration of learner characteristics and styles. Only by conducting a systematic investigation where learning variables are judiciously manipulated to determine their relative effectiveness and efficiency of facilitating specifically designated learning objectives will the true potential inherent in digital game design be realized.

6. Conclusion

Reasoning ability is an important cognitive skill for solving real-world problems and puzzle adventure games provide an enjoyable and engaging environment where players can experience different reasoning skills. In addition, it is known that people have different cognitive styles, so it is expected that people benefit unevenly in the same learning environment. To study the effect of puzzle adventure games on reasoning ability for players with different cognitive styles, we studied elementary students who are in the process of developing reasoning ability. We compared their pretest and posttest scores on reasoning ability, measured by SPM-P. We discussed several findings from our data. First, students in the puzzle adventure game group score reliably higher in the posttest than those who do not play the game. Second, FI participants benefit more than the FD participants with regard to improvement in reasoning ability after playing the puzzle adventure game. Lastly, FI and FD participants show different playing behavior patterns (i.e., global vs. linear).

Based on our findings, playing puzzle adventure games helps elementary school children improve their reasoning ability, especially for those who are FI. We feel it may be the case that these games are engaging, and students are able to interact with the game scenarios to see the outcomes of their actions immediately. Our work was designed to provide additional empirical evidence in game-based learning and expand the effect of game-based learning to learner factors (cognitive styles.) As mentioned in the future study, research studies can build on our results and techniques to deepen our understanding of game-based learning in action.

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