Effect of Computer-Based Video Games on Children: An Experimental Study

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ABSTRACT

This experimental study investigated whether computer-based video games facilitate children's cognitive learning. In comparison to traditional computer-assisted instruction (CAI), this study explored the impact of the varied types of instructional delivery strategies on children's learning achievement. One major research null hypothesis was tested: there are no statistically significant differences in students' achievement when they receive two different instructional treatments: (1) traditional CAI; and (2) a computer-based video game. One hundred and eight third-graders from a middle/high socio-economic standard school district in Taiwan participated in the study. Results indicate that computer-based video game playing not only improves participants' fact/recall processes ($F = 5.288$, $p < .05$), but also promotes problem-solving skills by recognizing multiple solutions for problems ($F = 5.656$, $p < .05$).

Keywords

Game learning, Play theory, Cognitive processes, Educational technology

Introduction

The use of multimedia in education has significantly changed people's learning processes. Results from a number of research studies indicate that appropriately designed multimedia instruction enhances students' learning performance in science, mathematics, and literacy (Gee, 2003). Previous studies indicate that computer-assisted instruction (CAI) programs have important factors that can motivate, challenge, increase curiosity and control, and promote fantasy in children (Tzeng, 1999). Despite the fact that computer and video games have the same multimedia capability as CAI programs, their potential learning impact is often discounted by parents and educators. Recently, computer-based video games' presence and popularity have been ever-growing, and game developers and researchers have started to investigate video games' impact on students' cognitive learning (Begg, Dewhurst, & Macleod, 2005; Squire, 2003; Vaupel, 2002). For example, Pillay commenced a study investigating the influence of recreational computer games on children's subsequent performance on instructional tasks (Pillay, 2002). While game-playing is regarded somewhat negative in educational settings, particularly for young children, re-scrutinization of its influence in a teaching and learning context is crucial.

This study investigated whether computer-based video games facilitate children's cognitive learning achievement. In comparison to traditional CAI programs, this study explored the impact of the varied types of instructional delivery strategies on children's learning achievement.

Research results from the Kaiser Family Foundation and the Children's Digital Media Centers (Rideout, Vandewater, & Wartella, 2003) found that children in the United States are growing up with media and are spending hours a day watching television and videos, using computers, and playing video games. According to the findings, today's children are starting to be exposed to technologies and media at a much younger age than previously thought. Therefore, educators' investigations become critical concerning the impact of technologies and media on children's development. This study investigates two main questions: (1) Can computer-based video games be instructional tools in early childhood education? (2) Should instructional strategies be modified to fit into young children's media experience?

Most previous research studies related to computer-based video games focused on the discussions of psychological study and child behavior (Provenzo, 1991; Squire, 2003). In psychological study, research results indicated that video games can promote hand-eye coordination, visual scanning, auditory discrimination, and spatial skills (Johnson, Christie, & Yawkey, 1999; Lisi & Wolford, 2002). For child behavior, evidence showed that violent video games may raise children's aggressive play and violent behaviors (Funk, 2001). Separate from previous research,

this study discusses computer-based video games from an educational perspective by exploring the following issues: (1) How might some of the motivating aspects of computer-based video games be harnessed to facilitate learning? (2) How might motivational components of popular computer-based video games be integrated into instructional design?

Research null hypothesis

Based upon the aforementioned purpose of study, one major research null hypothesis may be drawn. That is, there are no statistically significant differences in students' achievement when they receive two different instructional treatments: (1) traditional CAI; and (2) a computer-based video game.

Methods

Participants

The chosen participants were from a middle/high socio-economic standard school district in Tainan City, Taiwan. One hundred and eight third-graders participated in the study, 61 male students and 54 female students. The learning prerequisite for participants was the ability to use basic computer tools and Internet-browsing resources.

Instructional materials

The instructional topic used for this study was fire-fighting. Instructional content covered the basic knowledge about the danger of fire and fire-fighting techniques. The content was chosen because it covers a variety of educational objectives (facts, concepts, analyses) and is not related to the participants' courses, thus avoiding potential threats to internal validity of the study.

Two different instructional materials: computer-assisted instruction and a computer-based video game were used in this study. For the computer-assisted instruction, a unit of text-based instructional materials was developed. For the computer-based video game, Fire Department 2: Fire Captain, a 3D, real-time strategy game developed by Monte Cristo Games, was chosen for this study. This computer game has been assessed by the Pan-European Game Information (PEGI) age rating system, and has been approved for children seven years and older.

This 3D, real-time computer game applied the design principles derived from Keller's (1987) attention, relevance, confidence, and satisfaction (ARCS) model of motivation to facilitate children's learning. Below is a description of how the game's design strategies related to the ARCS model of motivation.
➤ Attention: The game created a 3D multimedia environment that generated multiple sensory stimuli to keep learners' attention focused. It also created an active learning environment by using simulation and role-playing strategies.
➤ Relevance: The game addressed the importance of fire-fighting and related safety issues before learners started to play the game. Also, a clear description of learning objectives was presented to connect the current topic with their prior knowledge and skills.
➤ Confidence: The game provided a variety of options according to learners' competence levels. For example, there is a tutorial game designed particularly for beginners not familiar with game playing.
➤ Satisfaction: After learners completed the game, several important statistics in the mission were reported, such as the total time spent on the mission, the number of people injured, the number of cars damaged, etc. This design strategy elicited learners' actual performance in the game and motivated them to play it again.

Independent variables

One independent variable was examined in this study: type of instructional treatments. Two groups (the computer-assisted instruction and computer-based video game playing) were identified for the variable of instructional treatment.

Dependent variables

The dependent variables used in the study were the outcome of participants' post-test scores and the results of the three sub-categories in the post-test. A post-test containing 28 items was designed for the study. It has a total of 100 points. The following details the three sub-categories in the post-test:
(1) Part 1: Multiple-choice (16 items): Part 1 measures knowledge of specific facts, terms, and definitions by asking participants to answer multiple-choice questions that relate to the topic of fire-fighting. The objectives measured in this test require an understanding of factual materials and concepts.
(2) Part 2: Matching (6 items): Part 2 evaluates participants' ability to associate specific terms from a list of appropriate context. The objectives measured in this test also focus on recalling facts and identifying factual information. The difference between part 1 and part 2 is that for matching up specific terms, participants need to analyze and compare the similarities and differences in the descriptions.
(3) Part 3: Application (6 items): In part 3, participants are required to demonstrate their understanding of how to put out a fire as a firefighter in an emergency scenario. This part requires that participants thoroughly understand the danger of fire, fire safety information, and fire-fighting processes during a rescue scenario. The test measures a higher-level cognitive task that shows understanding of what is being taught and its use in other circumstances.

Instructional treatments

The experimental study required 115 third-grade students to compare two different types of instructional treatment by looking at their learning performance. By using similar content, this study investigated which instructional treatment better affects students' cognitive learning (the computer-assisted instruction versus computer-based video game playing). Different instructional treatments were designed and selected for this study.

Control group

Participants in the control group (CG) learned by interacting with computers individually. The contents of the computer-assisted instruction in this study used a text-based format. The fire-fighting content was presented in a single web page without hyperlinks. The content included elements of fire, fire categories, fire-fighting techniques, and fire safety information. Participants determined their own reading pace by dragging the scroll bar on the right side of the web browser. No teacher was involved in this study, and the researcher provided only technical support to the participants when needed.

Experimental group

The purpose of this study was to determine whether computer-based video games support students' cognitive processes. With this hypothesis, a game called Fire Captain was chosen for the experimental group (EG). This computer game used similar instructional content as the control group. The primary goal of this game is to master all kinds of knowledge and skills to prevent fire. Although five single-player campaigns with increasingly complex missions constitute this game, the tutorial mission is one that participants have to play first in the study. In the tutorial mission, the participants learned everything they need to know to be a firefighter through each relevant and inclusive introductory task. Because Fire Captain is a real-time strategy game, the players needed to put out a fire at the end of tutorial mission, and their performance was graded by the game. To avoid interference with others, no teacher was involved in the experiment. As in the control group, the researcher provided only technical support to the participants when needed.

Experimental procedures

After obtaining approval from the Office for Regulatory Compliance from the researchers' universities, the researchers contacted the principal of the selected school in order to obtain a formal agreement for conducting this study. Two weeks prior to the formal study, parental consent forms were distributed to 136 students. These parental consent forms needed to be signed by the recruited students' parents.

Sampling for preliminary study

One hundred and fifteen students agreed to participate in this study and provided parental consent. They were randomly assigned into two groups, the control group ($n = 58$) and the experimental group ($n = 57$).

Procedures

Participants were asked to take part in two instructional sessions. Estimates were that each session would take 40 minutes (the length of a regular class period in elementary schools in Taiwan), for a total of 80 minutes. In the first session, the control group received a unit of computer-assisted instruction about fire-fighting. The experimental group was asked to play the computer game Fire Captain. In the next session, all participants were required to take a quiz to allow assessment of their learning achievements.

As the experiment began, the researcher asked the participants to turn on their monitors. For the participants in the control group, their monitors immediately showed a text-only web page. The researcher informed the participants that they would have 35 minutes to read through the instructions. The participants could browse the contents at their own pace. As soon as they finished the text-based instruction, they raised their hands to indicate to the researcher completion of the task. However, anyone who finished early had to remain seated and wait for the other children to finish until the time was up.

For the experimental group at the beginning of the class, the researcher used five minutes to demonstrate the skills of mouse control for the computer game. After the demonstration, the experimental group turned on their monitors, put on headphones, and began playing the computer game. The main menu of Fire Captain appeared on their monitors. Participants also had 35 minutes to explore this game freely. However, they had to finish the tutorial mission as soon as possible. How fast they completed the tutorial mission was a significant factor for evaluating their ranking at the end of the mission. Participants had permission to raise their hands at any time to ask for any technical support during this session.

After receiving various instructional treatments, each participant was required to take a quiz during the second session. The quiz was designed and developed to assess participants' learning achievements after finishing their instruction. From three categories of questions — fact differentiation/recall, analysis/comparison, and understanding/problem-solving — different types of learning outcomes were determined. The researcher graded and recorded all the post-tests.

Research design

This study investigated the effect of varied types of instructional treatments (computer-assisted instruction versus computer and video game playing) on individual learning achievement for third-grade students. This is a typical one-factor-with-two-levels experiment. Since the dependent variables are typically related statistically and conceptually (Yoder, 2002), the statistical correlation should be in the range of a low to moderate level (Tabachnick & Fidell, 2001). A multivariate analysis of variance (MANOVA) was performed to analyze the results. Furthermore, the real value of using MANOVA is in controlling Type I error (also known as false-positive error) while simultaneously analyzing multiple dependent variables.

Data collection

The data for this research was collected from a random sample of third-grade students enrolled in the selected school in Tainan City, Taiwan. One hundred and thirty-six third graders were expected to participate in this study. After contacting the participants' parents, 115 participants were able to participate. After instructional treatments and conclusion of the post-test, a total of 108 participants had completed the experiment. The drop-out rate for the study was 6.1 percent.

The data used for statistical analysis was collected from two sources: (1) the results of the post-test scores, and (2) the results of the three sub-categories in the post-test. The reliability analysis of the post-test showed internal consistency of the test scores. By using Cronbach's coefficient alpha, we reported an overall reliability of .88 for this study. Specific reliability for 16 items in Part 1: multiple-choice was .86, and for the six items in Part 2: matching, it was .71

Statistical data analysis

To test significant differences in learning achievement among the treatments (computer-assisted instruction versus computer and video game playing), a one-way multivariate analysis of variance (MANOVA) was performed. Multiple analysis of variance in Statistical Package for the Social Sciences (SPSS) was used to examine main and potential interaction effects of categorical variables on multiple interval/ratio dependent variables. That is, MANOVA tests for population group differences on several dependent variables simultaneously by creating vectors of the multiple dependent variables (Garson, 2005; Yoder, 2002). Thus, in conducting a one-way MANOVA for this study, we used various types of instructional treatments as independent variables (i.e., nominal scales); the outcome of students' multiple-measure scores of the post-test were the dependent variables (i.e., interval/ratio scales). An alpha level of .05 was set to analyze the significant difference of hypotheses. Prior to using MANOVA, the researcher examined the test results and found the distribution to be fairly normal with no extreme outliers.

From the results of the post-test (see Table 1), group means showed significant differences between the web CAI group ($M = 70.05$) and the video game group ($M = 76.18$).

Table 1. Descriptive statistics results of post-test

	Treatment groups	Mean	Std. deviation	*N*
Part 1 (0–64 points)	Web CAI	48.8421	8.27170	57
	Video game	52.2353	6.90098	51
	Total	50.4444	7.80766	108
Part 2 (0–18 points)	Web CAI	10.7368	4.70762	57
	Video game	11.7059	4.08066	51
	Total	11.1944	4.42900	108
Part 3 (0–18 points)	Web CAI	10.4737	3.85035	57
	Video game	12.2353	3.83452	51
	Total	11.3056	3.92561	108
Post-test total score (0–100 points)	Web CAI	70.0526	12.96068	57
	Video game	76.1765	10.76978	51
	Total	72.9444	12.31049	108

Correlations between multiple dependent variables

MANOVA assumes that multiple dependent variables relate statistically and conceptually (Yoder, 2002). According to this assumption, correlations between multiple dependent variables should be checked before MANOVA is conducted. As Table 2 indicates, most of the dependent variables have statistically significant correlations with one another ($p < .01$) in the range considered appropriate by Tabachnick and Fidell (2001).

Table 2. Correlations between multiple dependent variables

		Part 1	Part 2	Part 3	Post-test total score	Prior knowledge score
Part 1	Pearson correlation	1	.349**	.341**	.869**	.534**
	Sig. (two-tailed)		.000	.000	.000	.000
	N	108	108	108	108	108

Part 2	Pearson correlation	.349**	1	.301**	.677**	.239*
	Sig. (two-tailed)	.000		.002	.000	.013
	N	108	108	108	108	108
Part 3	Pearson correlation	.341**	.301**	1	.644**	.324**
	Sig. (two-tailed)	.000	.002		.000	.001
	N	108	108	108	108	108
Post-test total score	Pearson correlation	.869**	.677**	.644**	1	.528**
	Sig. (two-tailed)	.000	.000	.000		.000
	N	108	108	108	108	108
Prior knowledge score	Pearson correlation	.534**	.239*	.324**	.528**	1
	Sig. (two-tailed)	.000	.013	.001	.000	
	N	108	108	108	108	115

** Correlation is significant at the 0.01 level (2-tailed).
* Correlation is significant at the 0.05 level (2-tailed).

By examining the Levene's test of equality of error variances, the results showed that most of the dependent variables had equal variances ($p > .05$). Based on the above testing results, a one-way MANOVA could be conducted for data analysis.

Results of multivariate analysis of variance (MANOVA)

Table 3 reports MANOVA for the effect of the studied independent variable on the dependent groups.

Table 3. Results of multivariate tests

Effect	Wilks' lambda	F	p
Intercept	.022	1568.560	.000*
Treatment groups	.927	2.739	.047*

* Significant at .05 level

Table 4. Tests of between-subject effects

Source	Dependent variable	Type III sum of squares	df	Mean square	F	Sig.
Treatment groups	Part 1	309.911	1	309.911	5.288	.023*
	Part 2	25.276	1	25.276	1.292	.258
	Part 3	83.530	1	83.530	5.656	.019*
	Post-test total score	1009.413	1	1009.413	7.036	.009*
Error	Part 1	6212.755	106	58.611		
	Part 2	2073.641	106	19.563		
	Part 3	1565.387	106	14.768		
	Post-test total score	15206.254	106	143.455		
Total	Part 1	281344.000	108			
	Part 2	15633.000	108			
	Part 3	15453.000	108			
	Post-test total core	590872.000	108			

Univariate analyses, on Table 4, reveal that the dependent variables had significant main effects on the independent variables in all the tests except for the Part 2 test on treatment groups.

Findings and discussions

To accurately discuss the significant differences between various instructional treatments, the results of this study were subdivided into four sections: multiple-choice, matching, application, and the post-test total scores.

Finding 1: Multiple-choice - Univariate analysis results for Part 1 show that significant differences between treatment groups exist ($F = 5.288$, $p < .05$). Therefore, for Part 1, the null hypothesis should be rejected. Compared to the control group, the experimental group on average had a significantly higher score

Finding 2: Matching - Univariate analysis results for Part 2 show no significant differences between treatment groups ($F = 1.292$; $p > .05$). Therefore, for Part 2, the null hypothesis is retained. However, according to Table 1**,** the experimental group (mean = 11.71; standard deviation = 4.08) on average still had a slightly higher score than the control group (mean = 10.74; standard deviation = 4.71).

Finding 3: Application - Univariate analysis results for Part 3 show that significant differences between treatment groups exist ($F = 5.656$; $p < .05$). Therefore, for Part 3, the null hypothesis should be rejected. Compared to the control group, the experimental group on average had a significantly higher score.

Finding 4: Post-test total score - Univariate analysis results for the post-test score show that significant differences between treatment groups exist ($F = 7.036$; $p < .05$). Therefore, for post-test, the null hypothesis should be rejected. Analysis of the results shows that the experimental group, on average, had a significantly higher post-test score when compared with the control group.

Summary of findings

The statistical results clearly show a significant difference between computer-assisted instruction and computer-based video game playing in students' learning achievement (see Figure 1). Based on this finding, playing computer-based video games was determined to be more effective in facilitating third-graders' average learning outcome than text-based computer-assisted instruction. Therefore, it may be concluded that this null hypothesis should be rejected.

According to the results of post-test scores, computer-based video games can clearly facilitate students' learning performance. This finding indicated that computer-based video game playing not only can improve participants' fact differentiation/recall processes, but also promotes problem-solving skills by recognizing multiple solutions for problems. Additionally, more precise effects were detected by breaking the post-test scores into three sub-categories. When the researchers developed the items in Part 1, the objectives were to make the participants recall key facts, definitions, and concepts. As the results of Part 1 indicate, the participants in the experimental group have a better understanding of factual materials and concepts. Consequently, for finishing their mission, the participants in the experimental group know they have to memorize the key facts or concepts even if they were just playing a game.

The design of Part 2 is to measure the participants' ability to associate and analyze similarities and differences. Unfortunately, the results in this part are not as impressive as expected. According to the results, there is no statistically significant difference in Part 2, and the scores of the experimental group are only slightly better than the scores of the control group. Consequently, computer-based video game playing did not much improve participants' judgment. Two explanations are possible for this result: (1) insufficient descriptions or explanations of each key concept in the computer game, thus the participants in the experimental group did not have enough information to analyze and compare the differences, (2) the depictions of each item in Part 2 was not simple and easy enough for third graders to understand. Therefore, they were confused in making the right choice.
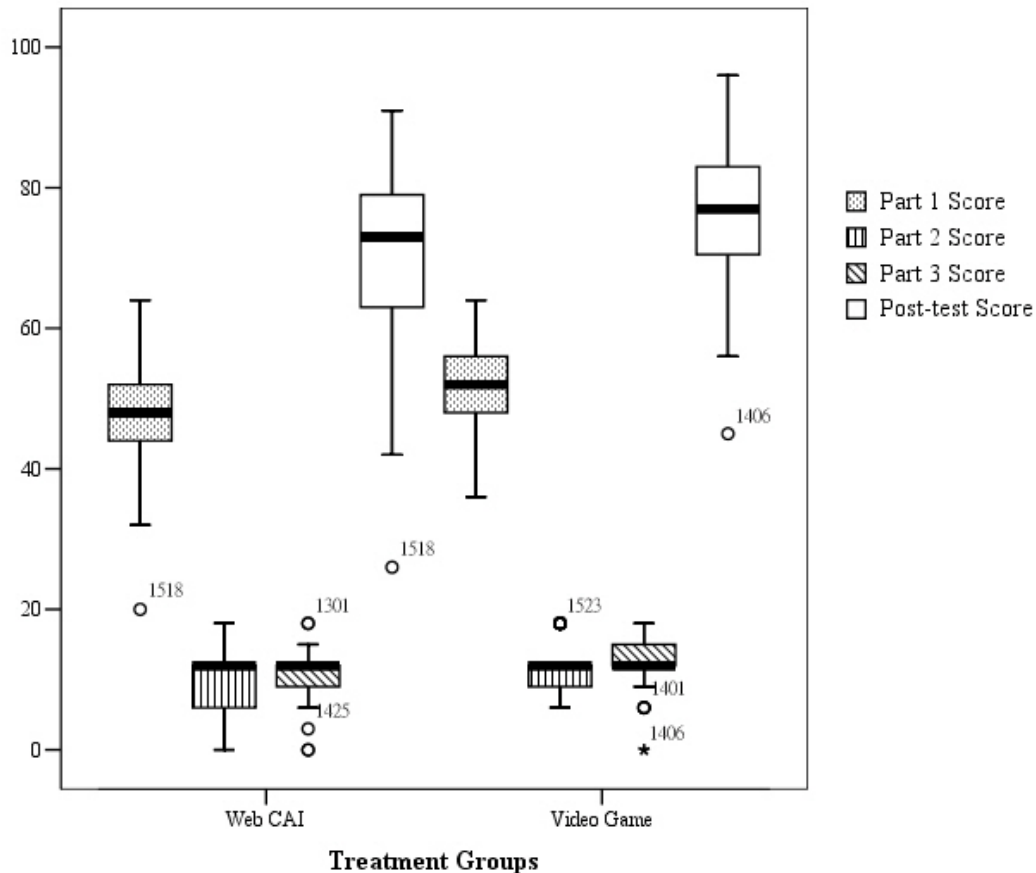
Figure 1. Box and whisker plot of test-score differences

The results in Part 3 are the most remarkable finding in this study. Apparently computer-based video game playing is effective for improving critical thinking and higher-level cognition. Part 3 was designed to identify the participants' comprehension, problem-solving, and strategy skills. The results indicate that participants' achievement of learning comprehension knowledge was enhanced. A number of research studies have been developed and explore better approaches to prompt student's higher-order thinking. With this finding, it may be concluded that computer-based video games can be considered an instructional approach to improve students' higher-order thinking.

In conclusion, computer-based video games might improve students' achievement in learning factual knowledge, problem-solving strategies, and higher-level cognitive thinking processes.

Limitations

Five limitations to this study became apparent when conducting the computer-based video game research and after reviewing the results.

First, all third-grade students had attended computer lessons and their ability to use basic computer tools and Internet-browsing resources were a prerequisite for participating in this study. One issue needs to be considered to ensure the validity of research design: for some students, Fire Captain was their first experience playing a computer game. Playing computer games is different from using an Internet-browser, and that could cause a problem for some students. Whether a student can successfully play the game in 40 minutes became critical for the willingness and ability of a student to finish this game.

Second, a 40-minute class for developing complex higher-order thinking and a post-test within 24 hours for measuring participants' outcomes may be inadequate. The amount of time for instruction should be taken into consideration for children's play in play theory. In particular, how much time a student spends on play or practice could be a major factor influencing children's motivation for learning and achievement. After all, human motivation is a function of human cognition involvement (McDevitt & Ormrod, 2004, p. 462). However, this study did not intend to address this question, although it will be an important consideration for future studies.

Third, the content of instructional treatments for this study could have been more objective. Fire Captain is not a game designed for instructional purposes. Also, the possibility of designing a website that could perfectly match all content with a computer game is likely impossible. In particular, different hypertext developed by different designers may result in different formats. To ensure that the design of the hypertext format and the content was consistent with the game, the instrument's validity needs to be examined further.

Fourth, from the results of this study, computer-based video games could function as powerful tools in assisting children's cognitive processes. However, an unanswered question regarding what could be the improved major cognition factor arising from playing computer-based video games — for example, short-term memory or long-term memory — needs further investigation.

Fifth, one methodological weakness of this experiment is that a sufficiently larger number of participants would be better so that the statistical test of effect size would have a higher partial Eta-squared value. However, the sample size was limited by the number of computers in a computer laboratory and the consent of students' parents. In Taiwan, the fact that some parents keep their children away from computer-based video games is well known. Without parents' understanding and support, difficulty arises for having a sufficiently large number of participants for similar future studies.

Conclusions

Different from previous studies that examined computer-based video games, this study was developed to investigate the effects of computer-based video games on the cognition of elementary-level students. Based on the aforementioned findings and the limitations of this study, the following conclusions may be drawn.

First, computer-based video games were applied to cognitive improvement. The results from this study provided experimental evidence to support that the use of computer-based video games can facilitate students' cognitive learning process. Few prior research studies dealing with computer-based video games explored the idea of learning. In fact, computer-based video games have often been criticized for reproducing violent action or behavioral aberration in most previous research reports. As this new form of technology has been treated as an entertainment device with negative influences on children, this study was attempted to restore computer-based video games to its original value: multifunction interactive media. In addition, given this approach, a different character emerges by suggesting multimedia's functionality and instructional capability should be considered equally with CAI programs.

Second, of great theoretical and practical importance, children's development and learning could benefit from play. Even without the emphatic educational intention such as CAI programs, children can still improve their cognition through playing computer and video games. Kids' play with computer games exemplifies forms of knowing and being in the world that are irreducibly and simultaneously social, technical, material, and symbolic (Mizuko, 1997).

According to the findings of the study, future research should continue to investigate the impact of computer-based video games along with different instructional strategies on varied children's learning achievements, such as facts, concepts, comprehension, problem-solving, or critical-thinking skills. Additionally, future studies should consider human factors in a gaming environment, such as learners' individual differences, learning styles, preferences in learning visual/audio materials, field dependence/independence, etc. Many of the independent variables associated with the study of human-computer interaction should be taken into account in the design of computer-based video games.

While computer-based video games may be manipulated to positively influence children's learning, particular attention must be given to guidelines derived from game design and experimental methodology, as well as to learner

characteristics and learning styles. Only by initiating a systematic program of investigation where independent variables are judiciously manipulated to determine their relative effectiveness and efficiency of facilitating specifically designated learning objectives will the true potential inherent in game design for learning be realized.

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