Using Computer-Based Math Games as an Anchor for Cooperative Learning

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Abstract: This paper reports an empirical experiment that examined the effects of cooperative computer-based math game playing, in comparison to cooperative paper-and-pencil drilling, on cognitive, metacognitive, and motivational math learning outcomes. 141 5th graders were randomly assigned to the two experimental groups and undertook the treatment activities for eight 45-minute sessions during four weeks. The results indicated that game-based cooperative learning context was more effective in promoting positive attitudes toward math.

Introduction

Despite the large number of studies about the use of instructional games alone and cooperative learning alone, studies combining these two variables are still limited. According to Crook (1994), computing technology may serve to support cooperation by providing students with something he calls points of shared reference. He further claims that in a traditional classroom situation there are not enough anchor points available at which action and attention can be coordinated for successful cooperation. In agreement with Crook's argument, an examination of the capability of using computer-based games as a mediating tool that help students to focus their attention to mutually shared objects (Jarvela, Bonk, Lehtinen & Lehti, 1999), thus enhancing their cooperative learning experiences, is warranted.

A major finding of the reviews and meta-analyses of CSCL studies (Cavanaugh, 2001; Whelan & Plass, 2002) is that there are very few real experimental studies comparing learning outcomes in between computer based and traditional learning situations. In most of the studies on CSCL the authors described the computer tools used and the working processes, but there was seldom rigorous experimental evidence about the effects of these learning environments. On one hand, the developers of CSCL environments were able to obtain a rich view into the interaction and collaborative knowledge-building processes through content analysis, ethnographic approaches, discourse analysis, as well as social network analysis; on the other hand, it is difficult to extract generalized main findings from this rich qualitative data (Koschman, Hall, & Miyake, 2002). Therefore, using the traditional experimental model of evaluating the effectiveness of the CSCL environment (such as cooperative learning around computer-based math games) is still a critical and complementary approach for the research community.

Research Purpose and Design

This research investigated whether cooperative computer-based math game playing, in comparison to cooperative paper-and-pencil drilling, would be more effective in facilitating comprehensive math learning outcomes. A pretest-posttest experimental design was used to examine the effects of two cooperative learning contexts (computer game-based playing and traditional paper-and-pencil drilling) on participants' performance at the criterion measures – standards-based math exam performance, attitudes questionnaire, and metacognitive awareness survey responses.

Participants

141 5^{th} graders were recruited from four rural school districts in America. Participants varied in gender, socio economic status, and prior math ability level: 51% were female, 38% were economically disadvantaged, and 43% were below proficiency in prior math ability level.

Computer-Based Math Games Used

ASTRA EAGLE was a series of web-based math games developed by the Center for Advanced Technologies at one of the sampled school districts. The games were designed to reinforce academic standards for mathematics required by Pennsylvania System of School Assessment (PSSA), which is a standards-based criterion-referenced assessment required by all public schools in the Commonwealth of Pennsylvania. The games were developed as single-player games using Macromedia's Flash and can run in any recent major Web browser.

In this study, four mathematics games within the ASTRA EAGLE set that target 5th grade students were used. These mathematics learning games contained a variety of tasks targeting math concepts comprehension and skills application. Most tasks were contextualized in roles and actions relevant to school students. For instance, in a game called "Up, Up, & Away" children acted as pilots who traveled by balloon. One problem embedded in the game was to estimate the traveling speed, "If the balloon was traveling at 14 miles per hour and then sped up by a factor of 2 and then added another 1 miles per hour, how fast would it be traveling?" Another example was the task of locating X and Y coordinates in a game called "Treasure Hunt", where game players could follow a hint "Go to X15, Y3 on the map" to dig for treasure. Immediate feedbacks were provided upon students' actions. The games were challenging: children had to push themselves to beat the computer game or get to the next highest level.

Instruments

A 36-item "Game Skills Arithmetic Test (GSAT)" was constructed based on the PSSA. It measured cognitive math skills that the computer games were designed to reinforce. The GSAT test was web-based and comprised 36 multiple-choice questions. A panel of 5th grade math teachers from the sampled school districts had vetted the content validity of the test questions. The KR-20 reliability of the test in this study was .86. An inventory on attitudes toward the subject matter was a modification of Tapia's "Attitudes Towards Math Inventory" (ATMI, Tapia & Marsh, 1996). This five-point Likert-scaled inventory is a 40-item survey, investigating students' feelings toward mathematics according to four identified factors labeled as: self-confidence, value, enjoyment, and motivation. The KR-20 reliability of the inventory in this study was .97. Metacognitive skill were measured by the Junior Metacognitive Awareness Inventory (Jr. MAI) Version A (Sperling, et al. 2002). The Jr. MAI Version A is a 12-item self-report questionnaire about the way students learn, intended for use in grades three through five. Respondents are required to estimate on a 3-point Likert scale (1 = never; 3 = always) the frequency with which they engage in metacognition when learning and studying. The instrument's reliability in this study was .65.

Procedures and Treatments

The researcher with the teachers administered GSAT, ATMI, and Jr. MAI as a pretest. Participants then were randomly assigned to one of the two experimental groups: cooperative game-playing group and cooperative paper-and-pencil drilling group. Participants received orientation to familiarize themselves with the cooperative learning task, and if applicable, the math games environment. Participants then were then required to play one math game during two 45-minute sessions each week for four weeks or do equivalent paper-and-pencil math drills during two 45-minute sessions each week for four weeks.

1. *Cooperative game playing*: A close simulation of the Teams-Games-Tournament cooperative learning strategy (DeVries & Slavin, 1976) was used. Specifically, students were stratified by their math ability level and gender, and then randomly assigned to a four- or five-member team. At the beginning of each game session, students collaborated with teammates for 15 minutes: sitting before the same computer and practicing with the games. For the remainder of the 30 minutes, game teams then competed against one another; each team member was assigned to a desktop computer at a tournament table to play against other teams' representatives. At any tournament table the students were roughly comparable in achievement level. At the end of every gaming session, the players at each table compared their gaming scores to determine their rank order which was then converted into points. The points that the players earned were added to compute a team score. The team scores were ranked and listed in a class newsletter, and distributed to the class at the beginning of next treatment session. Top team got a winner certificate.
2. *Cooperative paper-and-pencil drilling*: Like cooperative game playing group, participants formed heterogeneous teams (mixed in ability and gender) and did teams-games-tournament activities. The only difference is they did paper-and-pencil math drills instead of game playing. Drill questions were retrieved from the four math games in ASTRA EAGLE and printed on paper sheets.

After four-week experiment treatments, all participants retook the GSAT math test, ATMI attitudes inventory, and Jr. MAI metacognitive awareness inventory in the posttest.

Results

A single Multivariate Analysis of Covariance (MANCOVA) was conducted to examine the main effects of the cooperative learning contexts (computer-based game playing versus paper-and-pencil drilling on Game Skills Arithmetic Test (GSAT) performance, Junior Metacognitive Awareness Inventory score (JrMAI), and Attitudes toward Math Inventory score (ATMI). Participants' pre-treatment scores in GSAT, JrMai, and ATMI were used as covariates. The MANCOVA results indicated overall significant effects of the cooperative learning contexts on the outcome variables of mathematical learning, $F(3, 134) = 5.03$, $p < .01$. The results also indicated that cooperative computer-based game playing facilitated positive attitudes toward math learning significantly more than cooperative paper drilling ($F(1, 136) = 14.50$, $p < .001$), but its advantage on cognitive math test performance and metacognitive awareness was not significant ($p > .05$). Table 1 shows the descriptive statistics of the two experimental groups in terms of ATMI attitudes toward math inventory score, GSAT math test performance, and JrMai metacognitive awareness inventory score.

Table 1: Comparison of the two experimental groups

	Cooperative Paper-and-Pencil Drilling n = 67		Cooperative Computer-Based Game Playing n = 74	
	Mean	SD	Mean	SD
Pre Test				
Test [a]	18.00	5.70	18.97	5.46
Attitudes [b]	145.03	26.91	152.03	24.90
Meta-cognitive Awareness [c]	28.06	3.51	28.88	3.02
Post Test				
Test [a]	19.13	5.66	20.95	5.50
Attitudes [b]	144.73	28.88	161.76	23.38
Meta-cognitive Awareness [c]	27.45	3.77	29.01	3.46
Adjusted Posttest*				
Test [a]	19.66	--	20.47	--
Attitudes [b]	148.33	--	158.50	--
Meta-cognitive Awareness [c]	27.83	--	28.66	--

Note: * Adjusted means using three pretest measurements (GSAT, ATMI, Jr. Mai) as covariates.
a. The full score of GSAT math test is 36.
b. The full score of ATMI attitudes inventory is 200
c. The full score of Jr. Mai metacognitive awareness inventory is 36.

Based on this study results, it could be argued that using computer-based educational game as a motivational tool for cooperative learning is more convincing than using it as a cognitive or metacognitive one. There was no enough statistical evidence suggesting that computer-based game playing will facilitate or obstruct cooperative learning. However, it should be noted that the games used in this study were originally designed as single-player games. The game characteristics of a single-player game may influence its supremacy in serving cooperative learning format. Therefore cautions should be exercised when generalizing the study findings to interpret the interdependence between a multiplayer game and cooperative learning context.

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