Classroom Goal Structures for Educational Math Game Application

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Abstract. This field study investigated the application of cooperative, competitive, and individualistic goal structures in classroom use of educational math games and its impact on students' math performance and math learning attitudes. 124 5th-grade students were recruited and randomly assigned to a Teams-Games-Tournament cooperative, interpersonal competitive, or individualistic gaming condition. A state-standards-based math exam and an inventory on attitudes toward mathematics were used in pretest and posttest. Students' gender, socio economic status, and prior math ability were examined as the moderating variables. Results indicated that gaming in cooperative goal structure was most effective in promoting positive math attitudes while classroom goal structure for gaming had no significant impact on students' math test performance. It was also found that students of different socio-economic statuses were influenced differently by the gaming conditions.

Introduction

Educational researchers have proposed computer game as a powerful mathematical learning tool with great motivational appeal and multimode representations (Betz, 1995; Malone, 1981; Moreno, 2004). Scholars such as Rieber (1996) and Prensky (2001) theorized that games can serve as a vehicle for both play and imitation, two functions that Piaget (1951) considered crucial for a child's intellectual development. There were also a few empirical studies (Ahl, 1981; Okolo, 1992; Ota & Dupaul, 2002) showing that games can be effective tools for engaging math learners or supplementing the instruction of arithmetical concepts understanding and problem solving.

However, more researchers contended that the effectiveness of computer game on learning is still a mystery. The findings were often contradictory and the evaluations anecdotal or descriptive (Randel et al. 1992). The strict review of gaming studies conducted by Randel and his colleagues (1992) reported that among 68 studies regarding the effectiveness of games in terms of student performance compared with traditional classroom instruction, 38 (56% of the studies) found no difference, 22 (32%) found differences favoring games in student performance, and 5% found differences favoring conventional instruction. Similarly, the other three major reviews on educational games (Dempsey, et al. 1996; Emes, 1997) found no clear causal relationship between academic performance and the use of computer games. These gaming literature reviews indicated that educational researchers were still perplexed on how to incorporate computer games effectively into learning environment.

In an effort to solve the puzzle on the instructional use of computer games, some researchers (e.g., Almory, et al. 1999; Dempsey et al, 2002; Garris, et al. 2002; Rieber & Matzko, 2001) started the exploration of effective game characteristics design or game selection for learning purpose. Their research focused on more theoretical conjectures than field evaluations or in-situ implementations.

Differently, other researchers (e.g., Miller, et al., 1999; Papert, 1980) asserted that the investigation on computer games for learning should focus on how games can be carefully aligned with sound pedagogical strategies or learning conditions to be beneficial. Miller et al. (1999), Kaptelinin and Cole (2002) indicated that learning outcomes achieved through educational games depend largely on the instructional activities context that structure the way students use and interact with computer games. Consistent with this proposition, the investigation of game-based learning within alternative classroom goal structures – *cooperative, competitive*, and *individualistic* learning – becomes valuable (Johnson & Johnson, 1996).

Theoretical Framework

Effects of Goal Structures on Learning Achievement

The dynamics of classroom interactions is often an important feature in student motivation (Murphy & Alexander, 2000). One important example of the importance of social interactions is *classroom goal structure* – "the ways in which students will interact with each other and the teacher to achieve the goal" (Johnson & Johnson, 1999,

p. 3). Specifically, there are three choices in goal structure: cooperative, competitive, and individualistic. A *cooperative* goal structure is one in which learners perceive that they are working together with other students to gain rewards. A *competitive* goal structure is one in which learners perceive that they will be rewarded based on comparisons with other learners. An *individualistic* goal structure is one in which learners perceive themselves as working for their own rewards.

A host of research was conducted on the relative effects of cooperative, competitive, and individualistic modes of learning (Johnson & Johnson, 1994). Johnson and his colleagues (1981) conducted a meta-analysis of 122 studies related to classroom goal structures and concluded that cooperation is considerably more effective than interpersonal competition and individualistic efforts in promoting achievement and productivity.

However, few of these studies have been conducted in the setting of computer-enhanced instruction. Bahr and Rieth (1991) did a study related to the impact of classroom goal structures in computer-based drill-and-practice on high school students' math performance, and found no significant effects of goal condition. Hence, it is necessary to reexamine the influence of cooperative, competitive, and individualistic goal structures within a computer-enhanced instructional setting.

Learning Effectiveness of Educational Games

Use of computer games in education is widespread. Researchers (e.g., Amory et al, 1999; Betz, 1995; Malouf, 1988; McDonald & Hannafin, 2003) have conducted empirical research on computer games as an instructional tool. Dempsey and his colleagues (1996) reviewed some 100 articles related to instructional gaming. Randel and his colleagues (1992) conducted a meta-analysis of 68 gaming studies. These researchers found contradictory results concerning games' educational effectiveness. A possible reason is that the past gaming studies vary in goal structures for treatment gaming (e.g., cooperative or individualistic) and evaluation for learning outcome (e.g., cognitive performance or affective motivation). Thus, a study examining the effects of gaming within different goal structures on both cognitive and affective learning outcomes is warranted.

Educational Games in Different Goal Structures

Despite the large number of studies about the use of classroom goal structure alone and instructional game alone, studies combining these two variables are very limited. A recent review revealed only four related investigations (Leemkuil et al, 2003; Levy, 1990; Strommen, 1993; Tanner & Lindquist, 1998). Only two addressed the issue in K-12 math education settings. Closely related to the current study was Strommen's (1993) investigation, which examined 28 pairs of fourth graders using a cooperative and competitive educational computer game. In the cooperative condition, two students sat before one computer and played the game against the computer. In the competitive condition, each person had one computer and played the game against each other. The cooperative environment resulted in more correct answers than the competitive environment.

Teams-Games-Tournament Cooperative Learning Technique

Different from Strommen's research (1993), cooperative learning in this study was anchored in a cooperative learning technique known as Teams-Games-Tournament (TGT) (DeVries & Slavin, 1976), not previously researched in either meta analyses by Dempsey (1996) or Randel (1992). As Slavin (1995) suggested, TGT is a cooperative learning technique that has been widely investigated. Research (e.g., Ben-Ari, 2001; Slavin, 1995; Okebukola, 1985) indicates that TGT enhances students' academic achievement and attitudes toward the subject matter. However, most of these studies have incorporated TGT in traditional, face-to-face games rather than computer-assisted ones.

Confounding Factors

Although social interdependent theory suggests individuals in a cooperative structure, regardless of gender and ability, should experience enhancements in learning and attitudes toward a subject, there is evidence that the level of enhancement may vary across moderating factors (Johnson & Johnson, 1994). For instance, Johnson et al (1993) determined experimentally that low and middle achievers benefited more from cooperative goal structure than high achievers. Similarly, De Jean and his colleagues (1999) compared the reactions of junior high boys and girls to the same computer game and found that more boys were engaged by cooperative game-playing and group problem-solving. Similarly, Moreno (2002) reported that students with low prior knowledge and low computer experience were helped most by the visual representations in the gaming situation. His finding on the role of computer experience points to another potential mediating variable – socio-economic status (SES). SES has been related to computer experience level (Campbell, 1983) and hence may also mediate the effects of game-playing.

Research Purpose

Employing a pretest-posttest experimental design, this study examined the effects classroom goal structures for educational math gaming (TGT cooperative, interpersonal competitive, and individualistic gaming) on 5th graders' cognitive and affective learning outcomes (standards-based math exam performance and math learning attitudes). Students' gender, socio-economic status, and prior math ability were considered as moderating variables.

Method

Participants

One hundred twenty four participants were drawn from eight 5th-grade public school classes in central-Pennsylvania. Participants varied in gender (48% female) and socio-economic status (42% economically disadvantaged). All participants knew basic computer skills and had hands-on game-playing experiences in or out of class before the experiment. Participation was voluntary.

Materials

ASTRA EAGLE, a series of web-based computer games developed by the Center for Advanced Technologies of one sampled public school district in central-Pennsylvania, was used in this study. The games were designed to reinforce academic standards for mathematics required by "Pennsylvania System of School Assessment (PSSA)," a standards-based criterion-referenced assessment required by all public schools in the Commonwealth of Pennsylvania.

These games contained a variety of tasks targeting math concepts comprehension and skills application, including computation and estimation, adding and subtracting measurements, comparing quantities and magnitudes of numbers, and mapping X and Y coordinates. Most tasks were contextualized in meaningful stories relevant to school students. For example, in a game called "Up, Up, & Away", game players had to travel by balloon. One problem they met was to estimate the traveling speed, "If your 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 and dig for treasure" to win game credits. Immediate feedbacks were provided upon students' responses. Each game had multiple levels. To "conquer" a lower-level and "bump up" to higher-level one, students needed to answer all questions of that level correctly. The more levels one conquered, the higher score he/she earned.

Instruments

A web-based, 30-item multiple-choice "Game Skills Arithmetic Test (GSAT)" was researcher-developed based on the PSSA. It measured math skills that the games reinforced, including "adding and subtracting measurements," "comparing quantities and magnitudes of numbers," and "locating and identifying points on a coordinate plane" (Pennsylvania Department of Education, 2004). A panel of 5th grade math teachers from the sampled school district vetted its content validity. The GSAT was piloted with 548 5th grade students during the previous academic semester. KR-20 reliability was .80.

Tapia's "Attitudes Towards Math Inventory" was modified for a 5th grade audience (ATMI, Tapia & Marsh, 2004). This web-based, five-point Likert-scaled inventory contained 40-items investigating students' self-confidence, value, enjoyment, and motivation toward mathematics. This inventory reliably measured math attitudes with a Cronbach alpha of .97.

Procedure

Gender, socio-economic status, and previous PSSA math section percentile scores were collected prior to the treatment. The teachers administered the GSAT and ATMI as a pretest. Participants were randomly assigned by intact classes to one of three groups: Teams-Games-Tournament cooperative gaming (n = 43), competitive gaming (n = 41), and individual gaming group (n = 40).

Participants took two orientation sessions (40 minutes each) during which they read the guidelines and tried each web-based game. They were then required to play one math game during two 40-minute sessions each week for four weeks. Participants were seated in their own classrooms, each with an Internet-connected laptop. The teachers administered the treatments, setting up in-class game-playing sessions and monitoring participants' activities. The teachers also had a one-hour training session and were given administration job-aids. The researchers observed most game-playing sessions.

For the TGT cooperative group, a close simulation of the TGT structure was used. Specifically, students were stratified by their math ability level and gender, and then randomly assigned to a four-member team. At the beginning of each game session, students collaborated for 10-minutes in pairs, practicing with the game, discussing questions and solutions, and correcting each other's misconceptions. For the remainder of the 30 minutes, class teams then competed against one another; each team member held a laptop and was assigned to 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 two gaming sessions, 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 individual and team scores were ranked and listed in a newsletter, and distributed to the class at the beginning of every treatment week. In the newsletter, individuals were identified by pseudo IDs known only to themselves and their teammates.

During competitive gaming sessions, students were seated at their own desks and played games against the computer. At the end of every two gaming sessions, individual scores were compared against others in the class. Their individual percentile ranks, identified by their own names, were announced in a newsletter every week.

Similarly, students in the individualistic gaming group were seated at their own desks and played games individually. However, there were no individual performance comparison or ranking for their gaming performances. Finally, at the end of the four-week experiment, all participants took the post GSAT and ATMI.

Findings

Because the Pearson correlation coefficient (Pearson's r = .388) for the two dependent measures was far lower than .7 (Huch & Cormier, 1996), univariate analysis of covariance (ANCOVA) was conducted separately on the post GSAT and the ATMI scores to determine the main effect of gaming goal structure and the mediating influences of gender and socio-economic status (economic-disadvantaged and normal). Pretest scores and participants' previous PSSA math section percentile scores (as the index of prior math ability) were used as covariates. The prerequisite homogeneity of was confirmed before the ANCOVA was used. Descriptive statistics are presented in Table 1.

Table 1: Descriptive statistics for math performance and math attitudes

	Individualistic n = 40		Competitive n = 41		Cooperative n = 43	
	Mean	SD	Mean	SD	Mean	SD
Pre Test						
Performance	57.8	14.5	56.0	13.7	56.7	14.3
Attitudes	77.7	13.2	74.7	12.4	74.1	12.6
Post Test						
Performance	63.2	15.1	57.7	13.7	59.5	14.6
Attitudes	77.3	15.6	75.0	13.5	78.5	12.4
Adjusted Posttest Means*						
Performance	60.5	-- --	59.2	-- --	60.7	-- --
Attitudes	75.4	-- --	74.7	-- --	79.3	-- --

* = adjusted means using pretests as covariates.

The ANCOVA test on participants' GSAT math exam performance did not show significant effect of gaming goal structures (F = .26, p = .78). However, the other ANCOVA test indicated that gaming goal structures have a significant impact on ATMI math attitudes (F = 3.93, p = .02). Post hoc pair-wise comparison demonstrated that cooperative game playing promoted significantly more positive math learning attitudes (M_{coop} = 79.3) than the competitive and individualistic groups (M_{comp} = 74.7; M_{indi} = 75.4; p_{comp} = .01; p_{indi} = .04). No significant differences were found between the competitive gaming group and the individualistic gaming group (p = 0.70).

The test results also indicated a significant interaction effect between the gaming goal structure and socio economic status on participants' math learning attitudes (F = 3.85, p = 0.02). Specifically, economic-disadvantaged students gained more positive attitudes toward math in cooperative game-playing conditions than in the other two conditions (M_{coop} = 81.4, M_{comp} = 71.8; M_{indi} = 74.9). For economic-normal students there were no significant differences between the three gaming situations in promoting positive learning attitudes.

Besides, the study showed that educational math gaming, regardless of goal structure difference, generally enhanced boy students' math learning attitudes more than that of girl students (M_{boy} = 78.0 M_{girl} = 74.9, p = 0.05). But there was neither significant main effect of gender on test performance no evident interaction between gender and the treatment on both two learning outcomes.

Implications and Contributions

The most important implication of this work is to inform educational practitioners to be cognizant of the need to select appropriate classroom management strategies in integrating educational games into school education. As this study indicated, gaming goal structures, beyond the games themselves, yield significant effects on participants' math learning attitudes. Consistent with McDonald and Hannafin (2003), this paper recommends that educational practitioners use gaming within meaningful learning environments or tasks to promote learning.

Additionally, this study provides helpful findings on using Teams-Games-Tournament technique within a math learning setting. TGT cooperation is more effective than competition and individual condition in facilitating positive math attitudes, but not in promoting math performance. This discovery sheds light on one major controversy on cooperative learning – whether cooperative inter-group competition is advantageous over interpersonal competition (Reid, 1992).

Finally, in this study, a potential trend showing the economically disadvantaged students in cooperative game playing scoring higher in math attitudes than those in the other two conditions was evident. This is an interesting trend deserving further exploration.

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