

Gameplaying for maths learning: cooperative or not?

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Abstract

This study investigated the effects of gameplaying on fifth-graders' maths performance and attitudes. One hundred twenty five fifth graders were recruited and assigned to a cooperative Teams-Games-Tournament (TGT), interpersonal competitive or no gameplaying condition. A state standards-based maths exam and an inventory on attitudes towards maths were used for the pretest and posttest. The students' gender, socio-economic status and prior maths ability were examined as the moderating variables and covariate. Multivariate analysis of covariance (MANCOVA) indicated that gameplaying was more effective than drills in promoting maths performance, and cooperative gameplaying was most effective for promoting positive maths attitudes regardless of students' individual differences.

Introduction

The problem of low achievement in American mathematics education has been discussed in numerous policy reports (Mathematical Sciences Education Board, 2004). Educational researchers (eg Ferrini-Mundy & Schram, 1996) and administrators (eg Brodinsky, 1985), for years, have appealed for mathematics-education reform and proposed various solutions to foster mathematics learning.

Amongst these propositions were computer games as powerful mathematical learning tools with great motivational appeal and multiple representations of learning materials (Betz, 1995; Malone, 1981; Moreno, 2002; Quinn, 1994). Researchers reported (eg Ahl, 1981; Bahr & Rieth, 1989; Inkpen, 1994) that a variety of computer games have been used in classrooms to support learning of basic arithmetic and problem-solving skills.

Other researchers (Amory, Naicker, Vincent & Adams, 1999; Papert, 1980) contend that computer games need to be carefully aligned with sound learning strategies and

conditions to be beneficial. Consistent with this proposition, the incorporation of computer games within a cooperative learning setting becomes an attractive possibility. Cooperative learning in mathematics has been well discussed by Davidson (1990): group learning helps to remove students' frustration; it is not only a source for additional help but also offers a support network. Empirical research (Jacobs, 1996; Reid, 1992; Whicker, Bol & Nunnery, 1997) verifies the importance of cooperative learning in mathematics education.

Hence, the potential benefit of combining computer games with cooperative learning in mathematics warrants a field investigation. Specific research on the cooperative use of computer games is limited. Empirical study of this technique is especially sparse.

Therefore, the purpose of this research was to explore whether computer games and cooperative learning could be used together to enrich K-12 mathematics education. Employing a pretest–posttest experimental design, the study examined the effects of cooperative gameplaying on fifth-grade students' maths performance and maths attitudes when compared to the interpersonal competitive gameplaying and control groups.

Literature review

Computer games and cooperative learning

The use of computer games in education is widespread. Several researchers (eg Amory *et al*, 1999; Betz, 1995; Malouf, 1988; McDonald and Hannafin, 2003) have conducted empirical research on computer games as an instructional tool. Dempsey, Rasmussen and Lucassen (1996) reviewed some 100 papers related to instructional gaming. These authors found contradictory results concerning their educational effectiveness. In addition, in their metaanalysis of 68 gaming studies, Randel, Morris, Wetzel and Whitehall (1992) found that most or 36 reported no learning advantage to using games, 22 reported students using games outperformed their classmates in the traditional group, whilst 3 studies found differences favouring traditional instruction. Such diverse results may be because gaming researchers have used different configurations of games, such as networking or being competitive, or examined different outcomes such as exam performance or learning attitudes. Thus, a study examining the effects of different configurations of gameplaying on different types of learning outcomes is warranted.

Cooperative learning occurs in small groups of students who work together to maximise their own and each other's learning (Johnson & Johnson, 1994). Mathematics literature has acknowledged the positive effects of cooperative learning in improving achievement, attitudes, higher-order thinking skills and self-concept outcomes (Davidson, 1990; Jacobs, 1996; Reid, 1992; Whicker *et al*, 1997).

Despite the large number of studies about the use of instructional games and cooperative learning alone, studies combining these two variables are very limited. A recent review revealed only four related investigations (Leemkuil, de Jong, de Hoog and Christoph, 2003; Levy, 1990; Strommen, 1993; Tanner & Lindquist, 1998). Only two

addressed the issue in K-12 maths-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 to the questions within the game than the competitive environment. There was no control group.

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 metaanalyses by Dempsey *et al* (1996) or Randel *et al* (1992). According to DeVries and Slavin (1976), TGT has three basic elements: (1) *teams*—students are assigned to three-member teams randomised on equivalent achievement levels whose membership remains intact throughout the cooperative learning process, (2) *games*—skill exercises are played during weekly tournaments, (3) *tournament*—students represent their teams and compete individually against students from other teams. The winnings are brought back to their teams. Total winnings are tallied across teams and team champions are announced.

As Slavin (1995) suggested, TGT is a cooperative learning technique that has been widely investigated. Research (eg Ben-Ari, 2001; Okebukola, 1985; Slavin, 1995) indicates that TGT enhances students' academic achievement and attitudes towards the subject matter. However, most of these studies have incorporated TGT in traditional, face-to-face games rather than computer-assisted ones. Recently, Tanner and Lindquist (1998) investigated the application of the board game Monopoly as the context of TGT cooperative learning for college accounting majors. The nonexperimental, descriptive findings indicated students' attitudes were very positive towards accounting learning and perceived achievement. Therefore, a replication of early experimental studies of TGT in a new setting—education computer gaming for mathematics learning—should make a valuable contribution to understanding this cooperative learning technique.

Confounding factors in cooperative learning and computer-game application

Although cooperative learning theory suggests individuals, regardless of gender and ability, should experience enhancements in learning and attitudes towards a subject, there is evidence that the level of enhancement may vary across moderating factors (Johnson & Johnson, 1994). For instance, Johnson, Johnson and Taylor (1993) determined experimentally that low and middle achievers benefited more from cooperative learning than high achievers. The same results occurred with computer-game applications. De Jean, Uptis, Koch and Young (1999) compared the reactions of junior-high boys and girls to the same computer game and found that more boys were engaged in cooperative gameplaying and group problem solving. They also found that girls had trouble recognising the embedded maths elements in the game. Similarly, Moreno (2002) reported that students with low prior knowledge and 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 gameplaying.

Research design

Employing a pretest–posttest experimental design, the study examined the effects of gameplaying (TGT cooperative gameplaying, interpersonal competitive gameplaying, and no gameplaying) on two criterion measures (standards-based maths exam performance and attitudes). Students' gender and SES were considered as moderating variables, whilst continuous-scaled maths ability was used as covariate. Specifically, the researcher's expectations were that:

1. TGT cooperative gameplaying would result in significantly greater maths performance and maths attitudes than with competitive gameplaying, and both would perform significantly better than the no-gaming group.
2. Gameplaying would result in significantly greater performance and more positive maths attitudes for boys than for girls, and for economically disadvantaged students than economically normal students in the control group.

Method

Participants

One hundred twenty-five participants were drawn from six fifth-grade public-school classes in central Pennsylvania. Participants varied by gender (46% female), SES (45% economically disadvantaged) and race (8% minority). All participants knew basic computer skills and had hands-on gameplaying experiences in or out of class. Participation was voluntary. All students elected to participate, although absences during the pretest or posttest contributed to mortality (four and five participants missed the maths exam and the attitudes inventory respectively).

Materials

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

Four mathematics games within the ASTRA EAGLE targeted for fifth-grade students were selected (see: <http://eagle.aasdc.com>). They were single-user 'strategy games' that relied on thinking and problem solving (Crawford, 1984). These games contained a variety of problems, including measurement, comparing whole numbers, solving simple equations and mapping x and y coordinates. Most problems were contextualised in real-life stories relevant to school students. For example, in a game called *Up, Up, & Away*, gameplayers need to travel by balloon. One problem they met was to estimate travelling speed, eg 'If your balloon was traveling at 14 miles per hour and then sped

up by a factor of 2 and then added another 1 mile per hour, how fast would it be traveling?’ Each game had multiple levels. To ‘conquer’ a lower level and ‘bump up’ to higher-level one, students need 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 maths 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 fifth-grade maths teachers from the sampled school district vetted its content validity. The GSAT was piloted with 548 fifth-grade students during the previous academic semester. K-R 20 reliability was 0.80.

Tapia’s Attitudes Towards Maths Inventory (ATMI) was modified for a fifth-grade audience (Tapia & Marsh, 2004). This web-based, 5-point Likert scale inventory contained 40 items investigating students’ self-confidence, value, enjoyment and motivation towards mathematics. This inventory reliably measured maths attitudes with a Cronbach alpha of 0.97. Sample items include ‘I am able to solve mathematics problems without too much difficulty’ (self-confidence), ‘Mathematics is important in everyday life’ (value), ‘I am happier in a maths class than in any other class’ (enjoyment) and ‘I plan to take as much mathematics as I can in school’ (motivation).

Procedure

Age, gender, race, SES and previous PSSA maths-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: TGT cooperative gameplaying, interpersonal competitive gameplaying or no gameplaying.

Participants of the two gameplaying groups 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 maths game during two 40-minute sessions each week for 4 weeks. Participants were seated in their own classrooms, each with an Internet-connected laptop. The teachers administered the treatments, setting up in-class gameplaying sessions and monitoring the participants’ activities. The teachers also had a 1-hour training session and were given administration job-aids. The researchers observed most gameplaying sessions.

For the TGT cooperative gameplaying, a close simulation of the TGT structure was used. Specifically, students were stratified by their maths-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 representatives of the other teams. 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 pseudonyms (IDs) known only to themselves and their teammates, which was intended to ensure the *individual accountability* in cooperative learning (by having each team be aware of its members' contribution), whilst avoiding interpersonal competition (by hiding individual performances from the public) (DeVries & Slavin, 1976).

During interpersonal competitive gameplaying, 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 (so everyone could compare him/herself with other individuals), were announced in a newsletter every week.

In the controlled no-games group, participants took two 40-minute maths-drill sessions each week for 4 weeks. During the maths-drill session, participants completed paper-and-pencil maths drills that targeted the skills taught in ASTRA EAGLE. Finally, at the end of the 4-week experiment, all participants took the post-GSAT and ATMI.

Results

A $3 \times 2 \times 2$ multivariate analysis of covariance (MANCOVA) was conducted on the post-GSAT and ATMI scores to determine the effects of gameplaying (cooperative, competitive and none) and the mediating influences of gender and SES (economically disadvantaged and normal). Pretest scores and participants' previous PSSA maths-section percentile scores (as the index of maths ability) were used as covariates. Analyses of variance between groups on the pretest and PSSA scores indicated that there were no significant group differences at the pretest comparison. Two prerequisites, homogeneity of variances and the correlations between the two dependent variables, were confirmed before the MANCOVA was used.

The MANCOVA test showed an overall significant effect of gameplaying on participants' maths performance and maths attitudes ($F = 4.395, p = 0.002$). Descriptive statistics are presented in Table 1.

Hypothesis 1

Hypothesis 1: TGT cooperative gameplaying would result in significantly greater maths performance and maths attitudes than competitive gameplaying, and both would perform significantly better than the no-gaming group.

Table 1: Descriptive statistics for maths performance and maths attitudes

	Control		Competitive		Cooperative		Total	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
N	36		41		43		120	
Pretest								
Performance	61.2	14.4	56.6	13.2	56.7	14.3	58.0	14.0
Attitudes	77.5	9.38	74.7	12.4	74.1	12.6	75.3	11.6
Posttest								
Performance	58.2	15.2	57.7	13.7	59.5	14.6	58.5	14.4
Attitudes	74.2	12.0	75.0	13.5	78.5	12.4	76.0	12.7
Adjusted means^a								
Performance	55.3	—	59.9	—	61.2	—		
Attitudes	72.3	—	74.6	—	79.1	—		

^a Adjusted means using pretests and maths ability as covariates.

This hypothesis was partially supported. A main effect for gameplaying was found on both GSAT ($F = 3.81, p = 0.025$) and ATMI scores ($F = 6.81, p = 0.002$). Results from a post hoc pair-wise comparison on the adjusted posttest means showed that no significant difference was found for maths performance between cooperative gameplaying and competitive gameplaying ($M_{\text{coop}} = 61.2; M_{\text{comp}} = 59.9; p = 0.543$), but both performed significantly higher than the control group ($M_{\text{cont}} = 55.3; p_{\text{coop}} = 0.009; p_{\text{comp}} = 0.050$). Pair-wise comparison of attitudes indicated that cooperative gameplaying ($M = 79.1$) promoted significantly more positive maths attitudes than both the competitive gameplaying ($M = 74.6, p = 0.019$) and control groups ($M = 72.3, p < 0.0001$). No significant differences were found between the competitive gameplaying and the control group ($p = 0.239$).

Hypothesis 2

Hypothesis 2: the effects of gameplaying on students' maths performance and maths attitudes would be mediated by gender and SES.

This hypothesis was partially supported. The multivariate tests indicated no significant interaction effect between the treatment (gameplaying) and gender ($F = 0.518, p = 0.723$) on either maths performance or attitudes, nor was there statistical evidence indicating a significant interaction between the treatment and SES ($F = 2.251, p = 0.065$). Additionally, there were no indications of the main effects of gender ($F = 1.161, p = 0.317$) or SES ($F = 1.927, p = 0.151$).

However, the univariate tests did indicate a significant interaction between the treatment and SES on maths attitudes ($F = 3.415, p = 0.037$). As Table 2 reveals, economically disadvantaged students in cooperative gameplaying showed more positive maths attitudes than those in the other two conditions ($M_{\text{coop}} = 81.5; M_{\text{comp}} = 72.1; M_{\text{cont}} = 73.3$). For economically normal students there were no significant differences between the two gaming situations in promoting positive maths attitudes.

Table 2: *Adjusted posttest means of maths performance and maths attitudes by socio-economic status*

		<i>Adjusted posttest means</i>		
		<i>Control</i>	<i>Competitive</i>	<i>Cooperative</i>
Performance	Normal	54.8	56.7	59.3
	Disadvantaged	55.7	63.1	63.1
Attitudes	Normal	71.2	77.2	76.8
	Disadvantaged	73.3	72.1	81.5

Discussion

The findings showed that maths gameplaying did promote test-based cognitive learning achievement. Additionally, gameplaying context (TGT cooperative or interpersonal competitive) played a significant role in moderating the effect of educational gaming on affective learning outcome.

TGT cooperative versus interpersonal competitive learning

A host of research was conducted on the relative effects of cooperative and competitive modes of learning (Johnson & Johnson, 1994). Many researchers reported the superiority of the cooperative mode on learning outcomes, such as students' self-esteem (Johnson, Johnson & Stanne, 1986), productivity (Johnson, 1981) and test achievement (Mevarech, Stern & Levita, 1987). Differently, this study, conducted with computer games, found that the relative advantage of cooperative over competitive gameplaying on maths performance was not statistically significant.

On the other hand, the findings supporting the advantage of the TGT cooperative technique in promoting positive maths attitudes did confirm Slavin's (1995) claim that cooperative learning methods should provide both group rewards and individual accountability. In this study, the newsletters in TGT cooperative group carried both team and individual scores: the teams' ranks were known to the whole class, whilst the individual scores (matched with pseudo-IDs) were only known by individuals themselves and their own team. This arrangement thus offered both group rewards and individual accountability. Hence it was not surprising to find that TGT cooperative gameplaying was favoured over competitive gameplaying and the control group in terms of encouraging positive maths attitudes.

Computer games' instructional effectiveness

Rieber (1996) stated that play performs important roles in a child's psychological, social and intellectual development. Consistent with this proposition, many studies have demonstrated the instructional effectiveness of computer games (Dempsey *et al*, 1996). The findings of this study support these previous works. On the whole, gameplaying promoted test-based maths-learning achievement more than the no-gaming traditional practice.

Computer games can motivate learners through fantasy, being contextually relevant and appropriately difficult (Keller, 1987; Malone, 1981). In this study, TGT cooperative gameplaying and competitive gameplaying shared the first two motivational features (fantasy and relevance), hence this would engage learners more than in the no-gaming group. As for difficulty appropriateness, peer cooperation and tutoring in the TGT cooperative group may have made the maths 'appropriately difficult', whilst interpersonal competition provided no such support. The TGT group had 10-minute peer tutoring at the beginning of each gaming session, which may have helped to maintain gameplaying as challenging but attainable. In competitive gameplaying, such group support was missing. Therefore, it is not surprising to find that, in comparison to no gameplaying, the TGT cooperative gameplaying promoted both cognitive and affective learning outcomes, whilst the competitive gameplaying facilitated only cognitive achievement but not learning attitudes. It was because a key motivation component (appropriate difficulty level) may have been absent in the competitive gameplaying.

Individual differences and games application

This study showed that there were neither significant main effects of gender nor evident interaction effects between the treatment and gender on maths performance. This finding contradicted the report of De Jean *et al* (1999) that gender played a key role in learning effectiveness of the computer games.

Generally, not enough evidence was found on SES' main effects on maths performance for a definitive conclusion. However, univariate-tests data showed that students of differing SES may respond to gameplaying conditions differently. Specifically, cooperative gameplaying helped socio-economically disadvantaged students more in terms of facilitating positive maths attitudes. This is a new finding that has not been discussed in previous research.

Implications and further research

This study provides an argument for combining the two teaching techniques, computer games and cooperative learning, to improve maths education. The findings suggest that, regardless of gender, cooperative gameplaying is an effective strategy to promote students' maths learning, both cognitively and affectively. Another implication is that gameplaying conditions, beyond the games themselves, yield significant effects on maths performance. 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 TGT technique within a maths-learning setting. TGT cooperation is more effective than interpersonal competition in facilitating positive maths attitudes, but not in promoting maths performance. This discovery sheds light on one major controversy on cooperative learning—whether cooperative intergroup competition is advantageous over interpersonal competition (Reid, 1992).

Finally, in this study, although the influence of SES was not statistically significant in general, a potential trend showing the economically disadvantaged students in cooperative gameplaying scoring higher in maths attitudes than those in the other two conditions was evident. This is an interesting trend deserving of further exploration.

Continued research on gaming configurations can involve individual students who play by themselves. This enables a comparison of non-cooperative and noncompetitive conditions with the cooperative and competitive ones.

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