Main Takeaway: learning in games is best when fluidly integrated, aka, when the learning goal and the game goal are the same

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A case study of computer gaming for math: Engaged learning from gameplay?

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ABSTRACT

Employing mixed-method approach, this case study examined the in situ use of educational computer games in a summer math program to facilitate 4th and 5th graders' cognitive math achievement, metacognitive awareness, and positive attitudes toward math learning. The results indicated that students developed more positive attitudes toward math learning through five-week computer math gaming, but there was no significant effect of computer gaming on students' cognitive test performance or metacognitive awareness development. The in-field observation and students' think-aloud protocol informed that not every computer math drill game would engage children in committed learning. The study findings have highlighted the value of situating learning activities within the game story, making games pleasantly challenging, scaffolding reflections, and designing suitable off-computer activities.

1. Introduction

Recently computer games have been proposed as a potential learning tool by both educational researchers (e.g., Barab, Thomas, Dodge, Carteaux, & Tuzun, 2005; Betz, 1995; Gee, 2003; Kafai, 1995; Malone, 1981; Rieber, 1996; Squire, 2003) and game developers (e.g., Aldrich, 2004; Prensky, 2001). Frequently-cited arguments held by these researchers for using computer game in education are: (a) computer games can invoke intense engagement in learners (Malone, 1981; Rieber, 1996) (b) computer games can encourage active learning or learning by doing (Garris, Ahlers, & Driskell, 2002) (c) empirical evidence exists that games can be effective tools for enhancing learning and understanding of complex subject matter (Ricci, Salas, & Cannon-Bowers, 1996), and (d) computer games can foster collaboration among learners (Kaptelin & Cole, 2002).

Skeptics toward game-based learning contend that the effectiveness of computer games on learning is still a mystery. Several major reviews on educational games (Dempsey, Rasmussen, & Lucassen, 1996; Randel, Morris, Wetzel, & Whitehall, 1992; Vogel et al., 2006) indicated no clear causal relationship between academic performance and the use of computer games. A common skepticism on using computer games for learning purposes lies in the lack of an empirically-grounded framework for integrating computer game into classrooms. As Squire (2003) discovered, bringing a computer game into classrooms may raise as many issues as it solves. First, playing games does not appeal to every student. Second, students may be distracted by game-playing, and thus, not achieving the learning goals (Miller, Lehman, & Koedinger, 1999). Further, students may fail to extract intended knowledge from a complicated gaming environment (Squire, 2003). Finally, game design researchers (Smith & Mann, 2002) are worried that making games where the objective is to facilitate students' learning will risk sacrificing the game part along the way. Hence the very argument for using games for learning, that they are

and not every teaching method works

I feel like the arguments here are for replacing classroom learning rather than supplementing it

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engaging, vanishes along with the game part. Therefore, the key question remains misty: Do computer games really foster an engaging, effective learning experience in classrooms?

Limited studies were conducted to explore the above question. A recent review of game-based learning research indicated that most gaming studies focus on *learning conceptually* – concepts like general reasoning, creativity, system understanding and decision making, which does not demand special knowledge of subject areas (Bateson, 1972). Many current games used for facilitating learning lack connection to curricula in school. The content in these games are too general and inappropriate for fulfilling existing curricula (Egenfeldt-Nielsen, 2005). Differently, the present study emphasized the application of games in school education by exploring the potentials of games in facilitating the learning of math concepts and skills that are required by core curriculum content standards.

Certain researchers, such as Barab et al. (2005) and Squire (2003), did start to examine what happens with students and their learning processes in game-based curricula of mathematics, science, and history. Barab et al. (2005) built an educational adventure game (Quest Atlantis) from scratch while Squire (2003) customized a commercial off-the-shelf role-playing game (Civilization) for classroom application. Games used in both studies could be classified into simulation genre. As a complement to their works, the present study examined the use of puzzle games for drill and practice purpose. Two reasons underlie the selection of drill and practice games: (a) computer games have been used in education primarily as tools for supporting drill and practice, yet limited research has been done on the effectiveness of these games; (b) in comparison with simulation games, drill and practice games are easier to be introduced in a classroom and integrated into a traditional curriculum (Squire, 2003). exactly what I was thinking

Quite a few current researchers shy away from drill and practice games and have claimed them as not equally effective in improving learning and skills in comparison to other game genres. This claim, however, needs to be well evidenced by more empirical studies. The major meta-analyses of gaming studies (Randel, Morris, Wetzel, & Whitehall, 1992; Vogel et al., 2006) did not indicate significant effect of game genre itself on learning. Instead, many researchers indirectly assume that the major part of the game involves drill and practice elements that transfer facts and support skills (Garris et al., 2002). As Van Eck (2006) pointed out, the games environment is seen as one used to support not only the acquisition of process skills through simulation, but also the acquisition of foundational facts and automaticity in strategy application through drill and practice. Since not all games will be effective at all levels of learning, it is critical that we understand how different *types* of games work in order to align game taxonomies with learning taxonomies, rather than simply proposing and focusing on certain "Holy Grail" educational game types (Van Eck, 2006, p. 20). Hence, it is warranted to understand how drill and practice games work, what characteristics they embody, and what learners are doing as they play a game, thus informing whether and how drill and practice games would be a pedagogically sound learning environment.

Therefore, the current study investigated the application of drill and practice computer games in a summer school math program, by focusing on these research questions: (1) How did students interact with computer math games and game-based learning environment? (2) Did math game-playing improve students' math learning outcomes?

2. Methods

According to Ross and Morrison (2004), and Savenye and Robinson (2004), researchers in instructional technology should employ mixed, parallel methods to produce the most convincing body of evidence. Therefore, although the study adopted qualitative case study as the dominant paradigm in order to investigate a contemporary phenomenon – game-based learning – within its real-life context (Yin, 1984, p. 23), where possible, quantitative procedures were employed in the method of this study to corroborate and extend the primarily qualitative approach.

Qualitative data were collected in multiple forms – in-field observation, document analysis, and think-aloud verbal protocol – to achieve triangulation of data. The researcher subsequently conducted an analysis of themes in order to capture the essence of game-based learning through the voices of those who have participated directly in its implementation. Quantitatively, a within-group pretest–posttest comparison was made to investigate if students' math test performance, learning attitudes, and metacognitive awareness level improved through a game-based summer math program. was there a control?

2.1. Site

Wilson Elementary[1] in the sampled school district is an academic outperforming school that has consistently achieved higher levels of student reading and math proficiency score than demographically similar schools (65% compared with the state average 56%). The school is located in a rural area of Pennsylvania, with K-6 grades, 47% of students enjoying free or reduced lunch (namely socio-economic disadvantaged in this paper), and 97% of students being white. In the summer of 2005, the school held a math camp for students in 4th grade and 5th grade. Participation was voluntary. The camp was held from 10 am to 12 pm every Tuesday and Thursday for five weeks during the months of June and July. In this summer math program, all participants gathered in the school computer lab, each interacting with an Internet-connected desktop and playing eight ASTRA EAGLE math games over ten 2-h computer gaming sessions. During the open and the ending session, participants could choose to play whatever math games

[1] In this paper a pseudonym was used to replace the name of the sampling site.

(out of the eight ones); for the remained sessions they were required to play the games that was assigned to them. It was arranged that in each session participants played a different math game. Initial thoughts: potential bias, did they make sure kids were playing, kids might like videogames more now than 2005

2.2. Study participants

Fifteen 4th–5th grade students were enrolled in the summer math program and participated in this research project. They were 10–13 years old, with five being socio-economic disadvantaged, 10 being girls, and all being white.[2] Participants' pre-program school grades were collected. Their math abilities were classified into four levels – *advanced*, *proficient*, *basic*, and *below basic* based on their performances in the prior Pennsylvania System of School Assessment test. Out of the 15 students, four were advanced, six were proficient, and five were basic or below basic in math achievement. Participants were questioned on their prior gaming experience and if necessary, trained to know basic computer skills, such as using a mouse to click buttons on the computer screen. At the beginning of the summer math program, all participants took one orientation session to familiarize them with the gaming environment and were trained to do think-aloud, a strategy in which participants verbalize aloud while interacting with computer games, thus modeling the cognitive and affective processes of game-playing.

2.3. Games and instruments

ASTRA EAGLE, comprising a series of web-based games developed by the Center for Advanced Technologies of the sampled school district, was used in this study. 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 using Macromedia Flash and will run in any recent major Web browser. In this study, eight mathematics games that target 4th–5th students within the ASTRA EAGLE set were used. These mathematics learning games target a variety of math skills, such as measurement, comparing whole numbers, solving simple equations, and mapping *X* and *Y* coordinates. In some games, the targeted math skills were situated in meaningful experiences of role-playing an *identity* pertinent to school students, or embodied as *a strategy for accomplishing a goal* (Gee, 2003). For example, in a game called "Cashier", students played as a cashier that needs to do math calculation of money. Then in a game called "Treasure Hunt", students needed to perform the task of locating X and Y coordinates on a map in order to dig for treasure. In other games, math problems were presented in independent screens as puzzles to be solved. For example, one game was a Tic Tac Toe board game where a game player played against a virtual opponent and won by correctly answering math questions on the cards. Or in a game called *Up, Up, and Away*, game players had to answer a list of math questions before they could continue with the game play – traveling by balloon. Immediate performance feedbacks were provided upon students' actions, but these feedbacks only involved marking the answer correct/incorrect. Each game had score keeping and employed *progressive difficulty levels* – harder problems were presented at the higher levels of the game (Gee, 2003). To "conquer" the lower-level unit and "bump up" to a higher-level one, students needed to answer all questions of that level correctly. The more levels one conquered, the higher score he/she earns.

games seem fun for kids

To fully understand whether the computer math games promote learning, an evaluation of comprehensive learning outcomes of game-playing is necessary. Researchers (e.g. Barkatsas & Hunting, 1996; Mayer, 1998) have claimed that math learning depends on the development of all three components: "skill, metaskill, and will", or in other terms, the integration of cognitive, metacognitive, and affective affects (Mayer, 1998, p. 51). Although the games used this study concentrate on learners' practicing skills until they are nearly automatic (thus without conscious cognition or metacognition), this automatic level of mastery, as gaming researchers claimed, is achieved by iterative game cycles of cognitive assimilation or accommodation (Gee, 2003; Van Eck, 2006). That is, game play at each level exposes the players to new skills and allows them to practice this new skill set to an automatic level of mastery; they then move on to a new level and see the old skills be challenged and have to think again and learn anew (Gee, 2003). As such, game play involves attempt to fit new information into existing slots or categories (assimilation) and the process whereby players must modify their existing model to accommodate new information that does not fit into an existing slot or category (accommodation). Therefore, games get learners involved in constant analysis of their skills and strategies, testing, and revision; a major part of game play comprises cognitive and metacognitive activities during expertise/automaticity development. For that reason, the evaluation of games' outcomes in this study should be a comprehensive measurement of cognitive, metacognitive, and motivational aspects.

A 30-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 comprised 30 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 .82.

An inventory on attitudes toward the subject matter was a modification of Tapia's "Attitudes Towards Math Inventory" (ATMI, Tapia & Marsh, 2004). This five-point Likert-scaled inventory is a 40-item survey, investigating students' feelings

[2] When the study was conducted, there were only two black students in the 4th and 5th grade of the sampling school, and they did not volunteer to participate in the summer camp.

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 .90.

Metacognitive skill was measured by the Junior Metacognitive Awareness Inventory (Jr. MAI) Version A (Sperling, Howard, Miller, & Murphy 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 .64.

personal story: I liked playing math games as a child but at same point the game doesn't have what you're learning anymore

2.4. Data collection and analysis

All participants did the GSAT math test, ATMI attitudes inventory, and Jr MAI metacognitive awareness inventory as a pretest. They then played eight ASTRA EAGLE math games during 10 two-hour sessions for five weeks. After five-week gaming treatment, all participants retook GSAT, ATMI, and Jr MAI in the posttest. The questions of the GSAT test in the posttest were the same as that in the pretest, but the sequence of the questions were shoveled.

In-field observation, analysis of participants' game-playing records, and think-aloud verbal protocol were employed in the study to achieve a triangulation of qualitative data. Direct observation of the participants was conducted during every game-playing session. Concurrently, participants were asked to do think-aloud that helps to reveal their emotional situations and cognitive processes when interacting with game features, strategies to handle math problems in the games, and intentional or incidental knowledge constructed. Participants' game-playing logs, indicating their time logged into the game and gaming scores, were archived and analyzed every week.

Observation: The researcher closely observed participants' behaviors, verbal and nonverbal, and facial expressions when they interacted with the computer program, peers, and the external environment. A semi-structured observation protocol was developed to guide the researcher's attention during observation, though the actual observation was open to any situational changes.

sounds annoying and distracting

Think-aloud: Based on Ericsson and Simon's (1993) talk-aloud method, the researcher developed an open-ended protocol to facilitate participant thinking but not influence what they said. Participants were prompted to report whatever goes through their mind, such as what they were looking at, thinking, doing, and feeling, as they went about their task. The following instruction was given: "As you play the computer game today, please keep talking out loud everything that you think or do in playing. Try to say everything that goes through your mind, such as your thoughts, feelings, and choices about what you are doing and reading on screen." If the participants did not think-aloud, the researcher gave prompts like: "What are you doing now?" "Why did you do that?" "What made you arrive at this decision?" "How are you feeling?" or "So now you are..." Participants' verbal protocols were recorded with a mini-sized digital recorder. Efforts were taken to enable participants to generate a self-report of on-going actions without being interrupted or biased.

Document analysis: the computer game program recorded participants' on-task time (the time when they logged-in the games), the numbers of math questions they had tried to solve, the questions they had solved correctly, and the gaming scores they earned. These records were collected every week and coded.

Qualitative Data analysis: By following Yin's (1984) proposition on the case study method, the researcher first did within-case analysis to identify unique patterns within the data for the single case (participant), and then conducted cross-case thematic analysis to categorize the similarities and differences across the participants in responses and activities, with the goal of finding the recurring themes and organizing the data into systematic categories of analysis. The statements or meaning units that emerged as possible commonalities from the data were forwarded as initial themes (Creswell, 1998) and coded using Nvivo software. The researcher then refined these themes by removing overlapping ones and capturing the main thrust of each theme's meaning (Guba & Lincoln, 1994). Through this data coding process, general themes or patterns emerged and were synthesized.

2.5. Researcher's position

In order to immerse herself in the subjects being studied and gain an in-depth systematic study of the illustrative incidents, the researcher volunteered to be the assistant coordinator of the summer camp program, helping to set up and support the operation of every math gaming session. As Creswell (1998) pointed out, the problem of participant observation in qualitative inquiry was that the researcher's pre-understandings predisposed her to interpret the nature of the phenomenon. To *bracket* these predispositions, the researcher was explicit here. As a game player herself, the researcher was fascinated by the possibility of employing computer games as a potential instructional tool to enhance learning; however, she, at times, had concern over certain dreary educational games in which learning was only peripherally incorporated, hence felt less than completely comfortable with using computer games as a stand-alone instructional tool in the classroom. These tendencies certainly impact the data analysis and the resulting findings as they are part of the lens brought to the study. However, it is important to understand that these feelings did not remain unbracketed, but rather were part of the interpretation of the findings that emerged. Additionally, the researcher applied *member checks* – involving the participants in the inspection and rectification of transcribed think-aloud and observation data (Guba & Lincoln, 1994). The researcher had also tried to emerge herself into the site and the participant community before actual data collection, in order to reduce possible observer effects.

Table 1
Descriptive statistics

	Mean	Standard deviation	*N*
Pretest of GSAT[a]	15.9	5.6	15
Posttest of GSAT[a]	17.8	4.2	15
Pretest of Jr. MAI[b]	29.3	2.8	15
Posttest of Jr. MAI[b]	29.6	3.9	15
Pretest of ATMI[c]	149.8	24.6	15
Posttest of ATMI[c]	161.7	23.7	15

[a] The full score of GSAT math test is 30.
[b] The full score of Jr. Mai metacognitive awareness inventory is 36.
[c] The full score of ATMI attitudes inventory is 200.

Jr. Mai improved the least, but everything else improved

3. Findings and discussion

3.1. Quantitative results

A preliminary analysis of the data has been conducted to ensure compliance of the assumptions for the parametric statistics used in this study. The correlation analysis on the three dependent variables was also conducted for the multivariate statistics used in this study, and its result supported that the three dependent variables were significantly correlated. Table 1 summarizes the descriptive statistics for pretest and posttest on three dependent measures.

Then, a single repeated measures MANOVA was conducted to investigate whether math game-playing facilitated participants' math test performance, positive attitudes toward math learning, and metacognitive awareness level. The multivariate analysis indicted an overall non-significant effect of math gaming treatment on dependent measures, $F(3,12) = 2.28$, $p = .13 > .05$. Within the multivariate analysis, the univariate tests on three dependent measures indicated that there were no significant differences between participants' pretest and posttest performances in terms of GSAT math test and Jr. Mai metacognitive awareness survey. Therefore, there was no credible evidence suggesting that computer gaming facilitated students' achievements in cognitive math skills or metacognitive awareness. However, there was a significant difference between participants' pretest and posttest scores in ATMI attitudes measure, $F(1,14) = 5.34$, $p = .04$. Hence it can be concluded that students developed significantly more positive attitudes toward math learning through the math gaming treatment. which is important

The non-significant effect of computer gaming on math test performance in this study is congruent with the conclusion of major reviews on educational games (Dempsey et al., 1994; Dempsey, Rasmussen, and Lucassen, 1996) that there was no clear causal relationship between cognitive learning achievement and the use of computer-based games. Certain researchers (Azevedo, 2005; Pillay, 2002) have reported that learners interacting with hypermedia environment tend to be more intrinsically motivated and hence do metacognitive regulation more actively. Such a report is partially supported by the quantitative findings of this study. There is credible evidence supporting a significant effect of computer gaming on students' attitudes toward learning, but not on metacognitive awareness level. However, it should be noted that the reliability level of metacognitive awareness inventory was not satisfactory ($\alpha = .64$) and there may be a ceiling effect: in the measurement of metacognitive awareness before the treatment, the average group mean for self-reported inventory score was 29.3 (out of 36), which made it difficult to further improve the metacognitive score through a five-week treatment.

3.2. Qualitative results

Four general patterns on participants' experiences in game-based learning environment emerged through within-case and cross-case thematic analysis. These four patterns depicted how participants cognitively and affectively interact with the computer educational games of different designs, peers, and the offline classroom environment.

3.2.1. Learning outside of the gameplay versus learning within the gameplay

When asked about their feelings toward individual math games, what participants stated was usually either "It is fun" or "I feel bored, it needs too much calculation." They would not voluntarily comment about a game's educational values. This observation confirms Rieber's (1996) claim that most students differentiate gaming from learning, deeming the former as *play* and the latter as *work*. On the open day of the math camp, participants showed a lot of excitement, making such statements as, "so we will just play games? Cool..." But as time passed by, quite a few participants reported being disappointed and bored:

Multiple participants: Oh... they are learning games.
Amy,[3] 5th grade, proficient in terms of math competency: Can we play some other games?
Researcher: What kind of games do you want to play?

[3] In this section pseudonyms were used to replace the names of participants.

A: Well, games that are fun.
R: Do not you think this game is fun?
A: Kind of. But I do not like the questions in it. I had to think hard (about the questions).

Tom, 4th grade, basic in terms of math competency: Can I play other games on the Internet If I finish the first level of this game?

According to these participants, a learning game's engagement power would be spoiled if in this game students were asked to "step out of the game world" to do math learning (Van Eck, 2006, p. 22). For example, in certain games (e.g. Tic Tac Toe board game) students had to answer a list of math questions presented in a cut-scene that broke up the gameplay; to win the games they simply needed to solve math puzzles that were not situated within a game story or associated with a virtual *identity* or *character* (such as a cashier or treasure hunter). In other terms, with these games learning was not situated *in* but put *outside of* the gameplay. With these games, participants were observed to be less engaged and persistent, especially when time passed by and the games' novel sound effects, dynamics graphics, and other sensory stimuli became familiar, thus not attention grabbing. This observation explains why most educational gaming researchers recommend *learning by stealth*, that is learning can only be engaging when it is concealed within games and thus unconscious to the learners, when it is integral to the story of game world, and when it is designed as authentic activities associated with a virtual identity or character (Gee, 2003; Prensky, 2001). When facing a poor game design where the learning activities were not deftly veiled within the game world, participants reacted by deeming learning as a foe and chose to simply bypass it. Consequently, the wandering mouse – clicking the screen randomly to move around math problems presented – was a frequently-observed behavior. ha!

3.2.1.1. Wandering mouse – Random clicking. An analysis of participants' gaming records within a learning-outside-gameplay game indicated that for most participants, the ratio of math problems solved to problems tried was very low – one out of ten on the average, and time taken to solve a single problem was unreasonably short – usually in seconds. Such a pattern, as confirmed by the in-field observation, was mostly because participants took wild guess with math problems in the games. The design of the user input interface in the ASTRA EAGLE games – multiple-choice items – aided this wandering mouse behavior. When asked why and how they did guessing, the participants gave the following statements that could be classified into three conditions:

(1) A mismatching between challenge and ability:

- Jack, 5th grade, below basic in terms of math competency: It is too difficult. I even do not understand the problem.
- Ray, 5th grade, advanced in terms of math competency: (Recited the question) what is the next number in the following sequence? What is the next number in the following sequence? 101, 94, 80, 52...mm...101 minus 94, that will be 7...94 minus 7, that will be 86? Or no, that will be 87...87...mm...oh, it is not 7, so 101 minus 94 is 17? Wait a minute...it is 7. 94 minus 80, is 14...oh...I am confused. It is really confusing. All right, I will just guess. Is it B?

kids are funny!

These statements were in alignment with Malone (1981) and Gee's (2003) proposition on optimized challenge and pleasantly frustrating: the game's difficulty level should be appropriate with respect to players' levels, and game-based learning works best when new challenges are felt by learners to be hard but doable.

(1) Guessing being part of the gameplay
 Mary, 4th grade, basic in terms of math competency: I like guessing. Guessing is fun and I am good at it.
 R (encouragingly): You should think about this.
 M: But it is fun. Calculation is boring.As this conversation revealed, the participant deemed wild guess as a part of gaming "fun" or the gameplay, and even a knack for beating games.
(2) Avoiding cognitively-demanding tasks.

- Amy: I am not wildly guessing. I know it should be an answer smaller than 9. So it should be either C or D.
- David, 4th grade, proficient in terms of math competency: (Interpreted the question) so it is 9 feet 3 in. minus 6 feet 7 in. 9 minus 6 is 3. And 3 minus 7, 3 minus 7? Well, the answer should be 3 feet and ...inches. It should be A or B...I will try B...yeh...I got it. how tests work...
- Jeff, 5th grade, advanced in terms of math competency: (Recited the question) what is the next number in the following sequence, 1, 7, 31, 127? Huh, this one is easy. It is 511, C."
 Researcher: How did you know?
 J: The ending number. It is 1, 7, 1, 7, so the next number will be ended in 1, too. Huh, I got it right, and I do not need to do calculation.
 R: Are you sure this trick will always work?
 J: At least it works now.

Evidently, these participants were not cognitively engaged and had been avoiding steps that need a deep investment such as effortful calculation and problem solving. They picked up easy parts then left more complicated ones to guess and luck. Through the game-playing process, they became better gamers (rather than learners) by developing learning-irrelevant gaming skills. When asked how they were doing, they said, "We are better at answering the questions. We know the tricks." Cued guessing made game players earn gaming scores in an easy way, while impeding their effortful, math-learning-oriented cognition which should be imperative for valuable learning outcomes.

As observed, even when participants had actively interacted with a learning-outside-gameplay game (participants usually were able to complete or pass four game levels during a two-hour gaming session, as indicated by their game logs), their game-interaction performance did not guarantee a quality learning-engagement time due to wild guess behavior. This observation relates to what Lepper and Chabay (1985) have noted that whereas games may be engaging, a key question in applying computer games in education is "whether such potential motivational differences have important consequences for learning or retention" (p. 14). In this present case, there were clearly instances when motivation and effort were directed to activities that are not congruent with instructional objectives – wild guess, fun seeking, and avoiding mindful problem-solving.

3.2.1.2. Learning situated within the gameplay. In certain cases, learning tasks were integral to the game story. For instance, in a game called *Treasure Hunt*, participants needed to plot coordinates on an XY graph to locate treasure sites. Participants' think-aloud protocol clearly indicated content-related cognition when they played the game. For example:

> Sam: X9 Y7, X9, Y7 (repeating the question)... X is here...X1, X2, X3..X9; Y is going here, Y6, Y7. Yah, there...now I had to figure out how to get around the tree to go to Y7...got it (he was able to use the arrow key to move the shuffle around the tree and get it to the right spot) ...Y7(he was checking the Y coordinate)...X9(he was checking the X coordinate)...Yeah, I found the treasure!

As this example indicated, participants employed a series of cognitive thinking steps – question interpretation, principles execution, and self-monitoring with regular checking – when playing *Treasure Hunt*. A discussion capable of explaining this finding was by Rieber (1996) on *exogenous or endogenous fantasy* of gaming. In an exogenous fantasy context, learning activities that game players perform are not seamlessly integrated with or extensions of the fantasy roles they play in the game (Van Eck, 2006). For example, players may learn multiplications and by doing so win a board game or get continuing with the gameplay. This type of game, according to Rieber (1996), is likely to be more engaging than a long page of multiplications, but would not trigger a deep investment or an *extended engagement* (lots of effort and practice) on the part of the player (Gee, 2003). In contrast, in an endogenous fantasy game players learn and practice skills as a strategy to accomplish game goals or as a part of the game characters they take on, thus deeming learning as meaningful and intrinsically motivational functions (Gee, 2003). For example, players plot XY coordinates to locate treasure sites or calculate changes as a cashier. Therefore, it is no wonder that the in-field observation indicated that participants did a lot less wild guess in certain games where learning content is situated within the gameplay (e.g., *Treasure Hunt* and *Cashier*) than in other games where learning content is not integral to the gameplay (e.g., *Tic Tac Toe* and *Up, Up, and Away*).

It was also observed that participants tended to perform effortful game-based learning activities when they considered a challenge as within their regime of competence (Gee, 2003), or high-stake for accomplishing the game goal (e.g. solving this problem would decide whether they can pass a game level or not). For example, Mary, cited as frequently doing wild guess with questions in games, was observed doing effortful thinking with the questions that she had a sense of confidence about, "oh, because I knew everything about these questions". Then, it was found that participants generally invested a lot more time and efforts in the last one or two questions presented before the closure of a game level:

> Mark, 5th grade, proficient in terms of math competency: Great, with one more question I will be able to beat Fuzzy (the fictitious opponent in the game)...(read the question slowly)... "fall down by"...so it is a factor...minus, or no, it should be multiply...15 times 5...it is 60...Um, it is not there (in the multiple choices), so I must be wrong...all these numbers are small...so, it is divide...15 divides 5...it is 3...B! Yeah! I win, I win! aww

As this verbal protocol depicted, this participant was involved in effortful math problem solving due to his commitment to passing another game level. This observation confirms what Kernan and Lord (1990) and Gee (2003) noted that under conditions of high game goal commitment, individual players will enhance efforts and performance to game-based learning.

3.2.2. Gaming without reflection

It was found that when interacting with ASTRA EAGLE math games, very few participants reflected on their performance to gain lessons for future problem solving. They only attended to their feelings, by expressing happiness or disappointment with a success or failure, then moving on straight away. Both observation and think-aloud protocols indicated that most participants lacked a reflection process for performance analysis, new knowledge generation, evaluation, and integration, which are essential for *learning as a cycle of probing the world* – a major knowledge-construction format for game-based learning (Gee, 2003). The lack of reflection for game-based learning was mainly due to:

(1) Gaming reward mechanism: The games reward players based on the absolute total of items solved correctly, rather than a ratio of items solved to items tried. Therefore, to earn a higher gaming score, participants simply handled each item as quickly as possible:

> Sam, 4th grade, below basic in math competency: (spent one second viewing the question) oh my god, the problem is really long, too wordy. All right... (randomly clicked one choice)...oh, I win, yeah... (clicked the *Continue* button).
> Sam (after one unlucky trial): Oh, I got it wrong. Whatever...let's see this one... (started another question).

would no mc help?

total worse ratio better

It can be interpreted that the participant's desire to win altered his normal pacing at problem solving and cut off the valuable time for performance analysis and reflection. Like Sam, most participants revealed (in their verbal protocols) that they perceived beating virtual opponent (computer) as the major game goal, and were well aware that their performance would be rewarded in terms of quantity (e.g., the total of math items solved correctly) rather than quality (e.g., the proportion of the math items solved versus the items tried). This discovery verifies the claim of other gaming researchers (Garris et al., 2002; Locke & Latham, 1990) that goal and rules of the game govern where the players commit attention, motivation and efforts. It supports the recommendation that designers of educational games should set specific goal and rules that emphasize and extract desirable learning processes, such as encouraging reflection by embedding and rewarding reflection assignments (Swaak, van Joolingen, & de Jong, 1998).

(1) Feedback type: The feedback in the games is summative ("correct" or "wrong") rather than informative *elaborated feedback* (Kulhavy & Stock, 1989). As observed, when one solved a problem correctly, the computer screen would come up with a message of congratulations with hands-clapping sound effect; when one made a mistake, the screen would present a "you are wrong" message and indicate the right answer. No informative feedback or probing was presented (Gee, 2003). Participants did not get enough information or input to consider in retrospect. In most times, they could only comment, "Mm... Why is it ...? I do not understand...well, whatever..." This observation – the lack of informative feedback led to the absence of reflective learning – is consistent with the literature on the *debriefing* feature in instructional gaming design (Garris et al. 2002; Mayer, Mautone, & Prothero, 2002). According to Garris et al. (2002), the debriefing process – the review and analysis of events that occurred in the game itself – is critical in transforming game events into learning experience. And game-playing should be "coupled with the opportunity to reflect and abstract relevant information for effective learning to occur", through debriefing in system feedback, such as "a description of events that occurred in the game, analysis of why they occurred, and the discussion of mistakes and corrective actions" (Garris et al., 2002, p. 454).

3.2.3. *Play-based communication*

It was observed that collective game-playing facilitated peer communication. Over all of the two-hour gaming sessions, game players were very active in exchanging game scores, expressing feelings about the games, and in certain cases, doing social talk that was irrelevant to the learning tasks. However, these peer communications were mostly play-based rather than learning-oriented.

3.2.3.1. Peer scaffolding is not naturalistic. Both observation and think-aloud protocol indicated that elaborating mental process of mathematical problem solving was an effortful task for young participants. Without sustained encouraging and prompting, one could not enable a 4th- or 5th-graders to give mathematical thinking elaboration:

David: It is Choice B
Researcher: Why? How did you get this?
D: I did subtract. Subtract 5 feet 7 in. from 10 feet 2 in.
R: Why did you do subtract instead of add, or other operations?
D: Because...because you want to make the number small...
R: Why? Is there any key word in the sentence telling you that you should use subtract?
D: In the sentence, it said 'cut'.
R: I see. Then how did you subtract 5 feet 7 in. from 10 feet 2 in.?
D: 10 minus 5... and then 2 minus 7...wait, because 2 is too small, so you have to borrow 1 feet, so it is 12 plus 2, 14; then 14 minus 7 is 7, and then 9 minus 5, is 4 feet. So 4 feet 7 in.
R: Why it is 12 plus 2?
D: Because...

As this conversation indicated, cognitive elaboration was not naturalistic; skillful questioning or prompting was necessary to carry a thorough elaboration on all key cognitive steps for math problem solving. As observed, most participants revealed no awareness or skills to produce cognitive elaboration or prompt for cognitive elaboration production. In consequence, peer scaffolding was not an automatic occurrence. More often, a participant would simply throw answers on his/her peers, rather than explaining the mental reasoning or problem solving process: "Just trust me. Choose A," stated by Mark to Jack.

This observation on children being incapable or unaware of cognitive elaboration has not been well addressed in the literature. It indicates that the *inter-psychological function* (the ability or expertise emerges as distributed between people) is not a natural occurrence for certain population, especially young children (Vygotsky, 1978).

3.2.3.2. Boys versus girls. Interestingly, the researcher found that during game-playing boys tended to report information related to the games, such as game scores earned, game levels conquered, obstacles met, and tricks to handle the problems. By contrast, girls spent more time exchanging feelings and attending to social communication that was irrelevant to the games. Sometimes the researcher had to stop those game-irrelevant talks and remind them of the games. Such an observation confirmed the findings of earlier gaming studies (Greenfield, 1984; Inkpen et al. 1994; Tobin, 1998) that computer game is a facilitator for social communication and girls enjoyed game-playing particularly when given opportunity to socially interact with others. Consequently, it designates the potential of designing collaborative learning activities around game-playing.

On the other hand, the researcher did not observe obvious gender difference in terms of computer game preference. Both boys and girls expressed enjoyment with game-playing. There was no consistent pattern indicating boys and girls had different preferences among the eight math games used. It could be inferred that educational computer games are likely to be used in the classroom while not engendering the gender-oriented accessibility.

3.2.3.3. Quiet achiever. Among the group of game players, there was a quiet achiever – Brian. He always chose to sit in one corner and played the games by himself. He rarely talked to others during the game-playing process; neither would he proudly report his progress to the researcher, like some other kids would do. But his game-playing record indicated that he had a surprisingly high attainment in the number of math questions correctly answered. He was advanced in terms of math competency. When prompted, Brian could give a clear explanation of his mathematical thinking process, yet he rarely offered to help others. The researcher tried to encourage Brian to take peer collaboration, and arranged for him to sit beside the peers who could use his help. But it did not work as expected: Brian still chose solitary game-playing and would go back to his own corner at the next session. It can be interpreted that for such a quiet achiever, solitary playing seems the most comfortable and effective way to game-based learning. This also poses questions for future research on the role of individual differences as a mediating variable in game-based learning. Although it is generally accepted that computer games are engaging for many people, what is engaging to some people will not necessarily be engaging to others. Individual differences in learning style and personality traits such as competitiveness, curiosity, or sensation seeking may be predictive of preferences for game-playing environment, hence be predictive of learning effectiveness of certain game applications. However, research on this topic is lacking.

3.2.4. Offline learning tools

Another interesting finding from in-field observation was that participants used offline tools to assist online-game-based problem solving. Generally there were two formats of offline learning tool: technical tools such as pencil with paper or a calculator, and instructor's scaffolding.

3.2.4.1. Paper with pencil versus calculator. As observed, participants used calculators primarily. This was in large part due to the limitation of physical work space: game-playing took place in the school computer center where desk space was occupied by computers and keyboards, leaving no room for paper and pencil usage. In spite of the researcher's encouragement ("You can use paper and pencil"), most participants only used calculators. The exceptions were the ones with more advanced math competency, who used paper with pencil to lay out every mathematical computation step, then checked each step for any calculation or reasoning mistakes. It can be speculated that paper with pencil helped these participants visualize and monitor their cognitive model of math problem-solving. Participants who did not use paper and pencil hence missed a handy mapping tool, a tool that can help with cognitive modeling by assuming the lower-level burden of keeping track of arithmetic calculations so that learners can focus on higher-order thinking of problem analysis and solving. Therefore, a question germane to game-based learning is how the management of physical classroom environment and additional technological tools may supplement computer gaming to facilitate learning.

3.2.4.2. Instructor's guidance. Even though the games had been used as a stand-alone educational tool in the summer camp, the active company of an instructor or facilitator, as observed, was needed as an essential offline learning support, especially for students with lower prior knowledge. Jenna, 5th grade, below basic in terms of math competency, was one of the several participants who had actively requested for adult expert's help. The following dialogue happened when she was playing a game called "Up, Up, and Away", where game-players, in order to finish a balloon trip, have to solve problems involving addition, subtraction, multiplication and division of time.Jenna: This problem is difficultResearcher: Could you read it aloud?J (read the question): "If your balloon was traveling at 80 miles per hour and then slowed down by a factor of 5 and then added another 1 mile per hour, how fast would it be traveling?

R: Why do you think it is difficult?
J: ...Because it does not indicate the answer to the problem. I am confused.
R: Which part is confusing you?
J: 'Slowed down by a factor'
R: Do you know what "factor" means?
J: No.
R: Ok, factor is.... (Provided conceptual knowledge of 'factor')
When the researcher was doing the explanation, another participant picked up hand asking for help.
R (to the second help-seeker): Wait a second.
J: Oh, I got it. So I will multiply 80 by 5?

R: Are you sure?
J: Oh, wait…it said "slowed down"…(thinking)…so 80 divided by 5!?
R: Yes.
J: (used calculator) it is 16. I got it.
R: Wait, not yet.
J: Oh, I need to add 1.
R: Why?
J: Because it said "added another 1 mile".
R: There you go. Do you understand what "factor" means now? Can you handle similar problems in the future?
J: I think so.

teacher's are important

Researcher left Jenna and went to help another participant.

As the above scripts indicated, the facilitator had monitored game-playing student's problem-solving, helped problem analysis (by pointing out the confusing keyword "factor"), provided right instruction at the right moment (explaining the meaning of "factor" in the context of the specific problem), corrected errors, gave prompting questions ("Why do you…?") and immediate feedback. Such kind of guidance was common during all of the ten gaming sessions. But unfortunately, the facilitator was not able to provide individual tutoring/guidance to all needy participants.

The happening was caused by several reasons: first, the games' challenge level is not *optimized* – matching challenge with game-players' skill or ability (Malone, 1981); then, the games, developed solely for drill and practice, did not provide scaffolding cues or explicit instruction, such as individualized intelligent tutoring as suggested by ACT theory of cognition (Anderson, Boyle, & Reiser, 1985); finally, there was no effective peer tutoring between game-playing participants even through they were sitting close to each other.

Congruent with the perspective of Vygotsky's (1978) ZPD model, it can be argued that an instructor or facilitator, rather than a peer expert or a technological learning tool, has acted as the major scaffold for game-playing participants' cognitive development. This observation confirms the claim by Garris et al. (2002) that the value of the instructor in scaffolding learners is a critical (and somewhat overlooked) component in the use of educational games, as are learner support strategies such as online help, cues/prompts, informative feedback, and other activities.

4. Conclusions and implications

Conclusively, this study informed that computer math drill games, even through being more simplistic than commercial role-playing games in terms of visual, activity, and interaction design, still significantly enhance students' positive attitudes toward math learning. In addition, participants have performed committed and effortful on-task learning when playing certain games where math drills were integral to the gameplay and appropriately challenging.

However, it should be noted that not every computer math drill game would engage children in committed learning. The observation and participants' thinking aloud protocols have generally supported the propositions of gaming researchers (Garris et al., 2002; Gee, 2003; Van Eck, 2006) on good learning game design principles, such as situating learning activities within the game story and characters that players will take on, making games pleasantly challenging, and scaffolding reflections. In addition, the study findings also highlight the value of designing suitable off-computer activities that will enhance the game-based learning process, such as the usage of offline assistive learning tools, game-based collaborative activities, and the just-in-time guidance of an instructor.

As Garris et al. (2002) claimed, the design space for engaged learning through games application remains largely unexplored. A variety of issues concerning educational computer game design and application, as this study reveals, should be addressed in order to enable game-based learning experiences that are both engaging and effective. Explanation on these issues follows.

4.1. Integrating goals of gameplay and learning

Malone (1981), when exploring the motivational aspects of digital games, concluded that an engaging game should first present an obvious and compelling goal. However, for some games examined in this study, there was a discrepancy between the game goal and the learning goal. In consequence, learning turns to be an add-on that is against gameplay and to be avoided. When playing these games, participants were involved in activities that were not congruent with the learning goal, such as wild guess, avoiding effortful math-oriented cognition, and playing without effortful reflection.

A key solution to this learning-outside-gameplay problem, as demonstrated by the study findings and confirmed by other educational gaming researchers (Garris et al., 2002; Rieber, 1996; Van Eck, 2006), is designing *endogenous fantasy* – fantasy depends on the practice of skills, and vise versa. A good example of endogenous fantasy design is the game *Treasure Hunt* where the fantasy of locating and digging treasures depends on the skill of plotting XY coordinates, and the use of the skill, on the other hand, is applied on the fantasy world – an actual treasure site map. In contrary, in another game *Up, Up, and Away* the players' progress toward their game goal (travel to a place by flying balloon) depends on whether the players' answers to math questions (presented in a cut-scene) are right or wrong. In this exogenous fantasy case, fantasy depends on the use of the skill but not vise versa. Although exogenous fantasy seems a relatively easy way to overlay targeted learning content with a game, it is less effective in promoting learning. As in-field observation and think-aloud protocol indicated, participants performed obviously more wild guess and less math-oriented cognition in *Up, Up, and Away* than they did in *Treasure Hunt*. This qualitative observation, however, needs to be further verified through an experimental investigation on the effects of alternative game fantasy design (endogenous versus exogenous) on learning achievements.

Aside from designing endogenous fantasy, two other principles should also be respected to reinforce engaged learning in games: aligning the challenging level of a game with students' competency level, and carefully designing game-user interaction interface to hinder wild guess. For example, the user response format in computer educational games should not be multiple-choice items that enable random clicking.

4.2. Instructional support features in educational computer gaming

Educational gaming researchers (e.g., Garris et al., 2002; Gee, 2003; Gredler, 2002) have frequently cited debriefing or reflection as a critical element for game-based learning. However, participants may play a game without reflection. Possible debriefing and scaffolding features that encourage reflection in games, as implicated by the study results, can be: (a) informative feedback that is adapted to individual performance and provides error diagnosis; (b) explicit reflection assignment (coupled with corresponding incentive mechanism); (c) a cognitive modeling tool (or called *fish tanks* by Gee, 2003) that visualizes and abstracts relevant information to let the players see some of the basic variables from a sea of complex experience.

However, a concern on explicitly adding instructional support features into a computer game is that it may interfere with the optimal experience of *flow* – a high engagement state (Csikszentmihalyi, 1988), since "anything that causes us to 'leave' the game world interrupts flow" (Van Eck, p. 22). Having players pause or suspend the gameplay to do reflection is to some extent in conflict with the gaming researchers' proposition that we should integrate learning content into the game world by stealth so that younger learners, subconsciously, are engaged in repetitive play and hence repetitive learning. Will instructional support features appear so intentional and detached from the game world that they reduce a game's engaging power? Few gaming design theories or studies have well addressed this question. Further research is warranted to explore an appropriate equilibrium between explicit instructional support features and the engaging power of a game.

4.3. Game-based instructional strategies

The study results suggested that game-based learning is a hybrid, systematic process. While the structure of game events is derived from a digitally created game world, the games are framed by the players' real-life physical surroundings and the players' interactions with these surroundings. The dynamics of peer interaction, the active guidance of an instructor or facilitator, the access to additional technological tools, and the arrangement of physical classroom environment have all influenced game-based learning experiences. As Miller et al. (1999), Kaptelin and Cole (2002) argued, learning outcomes achieved through educational games depend largely on the instructional activities context that structures the way computer games are used in classrooms. Therefore, investigation on educational computer gaming should focus on not only how games can be designed for learning purpose, but also how games can be carefully aligned with sound instructional strategies to be beneficial.

Specifically, the researcher would propose that to produce effective learning collaboration and peer tutoring around game-playing, explicit training on how to conduct cognitive elaboration and tutoring should be provided to students. More importantly, the instructor should play an active role in facilitating and regulating game-based learning process rather than being a standby observer.

As Rieber (1996) and Okan (2003) claimed, designing and using computer games for learning is more than a form of educational "sugar coating". This study evidenced that only with a careful design of game fantasy, learning support features, and game-based pedagogy, could games trigger deep learning that is itself *part and parcel of* the engagement (Gee, 2003).

4.4. Limitations

It should be emphasized that this is a case study of one specific set of learning games with a small sample of students who, even though diverse in gender, socio-economic status, and prior math abilities, were from the same school that has consistently achieved higher levels of student proficiency score than demographically similar schools. Cautions should be exercised when generalizing the study findings to interpret the interaction between other types of games (e.g. multiplayer role-playing games) and student population of different characteristics.

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