# Examining a Conceptual vs. a Computational Design on Understanding in a Mathematics Game

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**Abstract:** This paper examines the effect of different learning mechanics on middle school students' learning outcomes and motivation in two versions of a mathematics videogame designed to teach the properties of angles. One version was computation-oriented and required players to choose a correct numerical answer that solved an unknown angle. The second version was identical, except that players were required to choose the correct conceptual rule that would apply to finding the solution for an unknown angle. The impact of these two game versions was subsequently analyzed to determine their effect on two dependent variables: learning, and motivation. Results from N=194 sixth and seventh grade students, randomly assigned to play one of the two versions of the game, suggest that the learning mechanics studied affect how much students learn, favoring the computation-oriented game version. Implications of these findings are discussed within the context of educational game design.

## Introduction and Background

In education, an important distinction is often made between procedural and conceptual knowledge. Procedural knowledge is the ability to execute action sequences to solve problems whereas conceptual knowledge is implicit or explicit understanding of the principles that govern a domain and of the interrelations between units of knowledge in a domain (Rittle-Johnson, Siegler, & Alibali, 2001). In general, conceptual knowledge is known to generalize to other contexts whereas procedural knowledge consists of action sequences that may be memorized without a firm understanding of the concept (Rittle-Johnson, Siegler, & Alibali, 2001). In mathematics, conceptual knowledge is flexible and generalizable as opposed to procedural knowledge, which is tied to specific problem types (Hiebert & Lefevre, 1986). Given these important properties, the National Council of Teachers of Mathematics (NCTM) emphasizes the importance of students developing a conceptual understanding of mathematics (NCTM, 1989, p.17).

In mathematics classrooms, procedural approaches are often used. However, research has shown that students who learn in a conceptually oriented mathematics classes outperform those who learn in procedurally oriented classes and have more positive attitude toward mathematics (e.g., Boaler, 1998; Masden & Lanier, 1992). Given the importance of conceptual learning approaches and a tendency of teachers to rely on procedural practices, is it possible to create a more conceptually focused learning experience in an educational videogame about mathematics?

Many researchers have been advocating digital games as engaging tools for learning of various concepts, including mathematics (e.g., Gee, 2008; Squire, 2005). Players may learn different types of knowledge in several ways (e.g., through narrative, game mechanics etc.) while they play games (Turkay & Adinolf, 2012). Ideally, the learning aspects of a game should be integrated in a way that they become an integral part of the game play and not merely an addendum to the game mechanic (Kinzer et al., 2012; Plass et al., 2011). This concept also relates to exogenous v.s. endogenous fantasy in educational games (Malone & Lepper, 1978). Exogenous fantasy is when the gameplay is separated from the educational content of the game whereas endogenous fantasy is when the gameplay is connected to the educational content. However, the majority of mathematics-content commercial educational games target automaticity in strategy application through drill and practice rather than focusing centrally on the introduction and development of concepts. In other words, they are more concerned with players' procedural knowledge than conceptual knowledge as it is often challenging to make conclusions about learners' conceptual understanding based on the product of a procedurally oriented mathematics questions. While games in the domain of mathematics aim to motivate students with various external rewards (e.g., points, positive feedback) that may harm intrinsic motivation (Deci, Koestner, & Ryan, 2000), many also fall short in promoting higher order thinking by targeting mostly procedural knowledge gain.

One way to achieve cultivation of conceptual knowledge that can facilitate a balance between conceptual and procedural knowledge may be to design games by utilizing learning mechanics. Learning mechanics may be thought of as patterns of behavior that form the essential *learning* activity that is repeated throughout a game (Plass et al., (2013), see p. 698). Since learning mechanics are concerned with learning as the primary objective, they must be rooted in a learning theory. For example, using a social-cognitive theory, a game might draw on the well-documented instructional practice of peer-tutoring (see Topping, 1988). The specifics of how peer-tutoring is integrated into a game is the business of game designers, but one possibility might be to require players to generate authentic problems to be solved by other players, thus establishing a peer-to-peer interaction. Regardless of the specifics, an effective educational game will use learning mechanics to present to-be-learned content as well as specific user actions (game mechanics) to foster the acquisition of related knowledge or skills (Plass et al., 2012, p. 65).

We examine herein whether implementing different learning mechanics in games, i.e., learning mechanics that focus on either procedural or conceptual knowledge, results in different outcomes. To do so, we used two versions of the same game to systematically alter the learning approach integrated into each version. The first (arithmetic) version uses a procedural learning mechanic, requiring players to solve problems through computation and calculation. In this version, players submit specific numerical answers in order to advance in the game. The second (conceptual) version, is identical in terms of look, feel, and content, but requires players to solve problems through the application of conceptual rules.

Thus, this study explores the following general question: Given game designers' ability to "design the structures and contexts in which play takes place" (Salen & Zimmerman, 2004, p. 67), what is the potential and appropriate use(s) of varying learning mechanics to address learning and motivation? The following, specific research questions are: RQ1: How do differing learning mechanics affect learning outcomes? RQ2: How do students' subjective experiences change as they advance in the game with different learning mechanics?

## Methodology

## Design and Participants

To explore the above-noted questions, a two-factor study with a quasi-experimental design was conducted. Two hundred and twenty six (n = 226) sixth and seventh grade students were randomly assigned to one of two conditions based on the learning mechanic integrated into the game: conceptual and arithmetic. Due to participants' absence either during the pretest or the posttest, 32 participants' data were removed from the analysis. In the end, 194 participants' data were analyzed across the conceptual version (CV: $n$ = 84; f = 48, m = 36) and arithmetic version (AV: $n$ = 110, f = 54; m = 56).

In a preliminary analysis to examine equivalence between groups, statistically significant age difference were found ($M_{CV}$ = 10.80, $SD$ = 0.41; $M_{AV}$ = 11.92, $SD$ = 0.84; $t$ = 12.19, $p$ < 0.001), but the difference in ages was not a concern as the important factor under study was mathematical knowledge related to angles. However, a pretest determined that there was a statistically significant difference in relevant mathematical knowledge of angles between groups. Thus, as will be shown later, a covariate statistical analysis was used to control for pretest-determined group differences.

An independent samples $t$-test comparing the pre-test scores (Set 1 and Set 2) of CV and AV showed statistically significant differences. Specifically, students in AV's pre-test scores were statistically different than students in CV ($p$ < 0.001, $t$ = 6.52, $M_{AV}$ = 10.04, $M_{CV}$ = 7.42; $p$ < 0.01, t = 3.19, $M_{AV}$ = 2.13, $M_{CV}$ = 1.37; $p$ < 0.05, $t$ = 2.52, $M_{AV}$ = 1.06, $M_{CV}$ = .7). Thus, an analysis of covariance (ANCOVA) was used.

## Procedure

The experiment lasted two days, consisting of two, approximately 60 minute instructional periods. Day 1 consisted of introducing participants to the project, answering their questions, and conducting a 15-minute pre-test on their knowledge of the game's educational content (these related to standards 4.G, 4.MD, 4.OA, 5.G, 7.G, and 8.G in the National Governors Association Center for Best Practices, 2010). The paper-based pre-test consisted of 21 questions. On Day 2, participants were given one, 30-minute play session followed by a paper-based post-test. Day 2 activities took place at the school's computer lab. At the beginning of the play session students were told that the game consisted of six chapters and that each chapter had eight to ten levels. They were instructed to advance as far as possible in the game in the allotted time. During game play, participants worked individually, each at one computer console. Each player was given headphones so they could hear the game's audio, and "scratch" paper for their use, if desired. After thirty minutes of play, students were asked to exit the game. At this point, students were given approximately 15 minutes to complete a paper-based post-test which has the same type but different questions.

## Instruments and Measures

### *Educational Video Game*

The educational video game used for this study was *Noobs vs. Leets: the Battle of Angles and Lines*, developed by researchers at the Games for Learning Institute (G4LI), previously shown to be an effective educational intervention (see Plass *et al.*, 2011b). The game is designed to teach angle rules and has a simple story in which players help characters called "Noobs" save their friends trapped in various places on the screen by unlocking paths. The paths are unlocked by solving for unknown angles. The game has six chapters and each chapter introduces the player to a new concept about angles. For example, the first chapter starts with types of angles (e.g., acute, obtuse, right, straight) and their numerical degree values. As players progress through the chapters they are shown and required to use more complex rules and concepts such as complementary, supplementary, and vertical angles. In the beginning of each chapter, players are provided with a short (approximately 90 second) video tutorial about the new angle feature introduced in that chapter. The game increases in difficulty with each chapter.

For this study, two different versions of the game with differing learning mechanics were used. We refer to these as the Conceptual Version (CV) and Arithmetic Version (AV). The CV used the learning mechanic: *Apply Rules to Solve Problems*: Learner selects the correct rule to solve the given problem (Plass et al., 2011). In the AV the learning mechanic is: *Calculate the Correct Answer*: Learner selects the correct answer to the target problem. In the CV, players solve missing angles by identifying the correct rule or concept among several possibilities. For example, to solve the highlighted locked angle in the different versions of the game in Figure 1, AV participants have to click on the locked angle, calculate the answer and select the answer from given choices on the left hand side of the interface. In the CV, participants have to click on both the locked angle and its complementary angle. Then, without a need for calculation, they select the rule from given options that would be the basis for a calculation that would correctly answer the question.

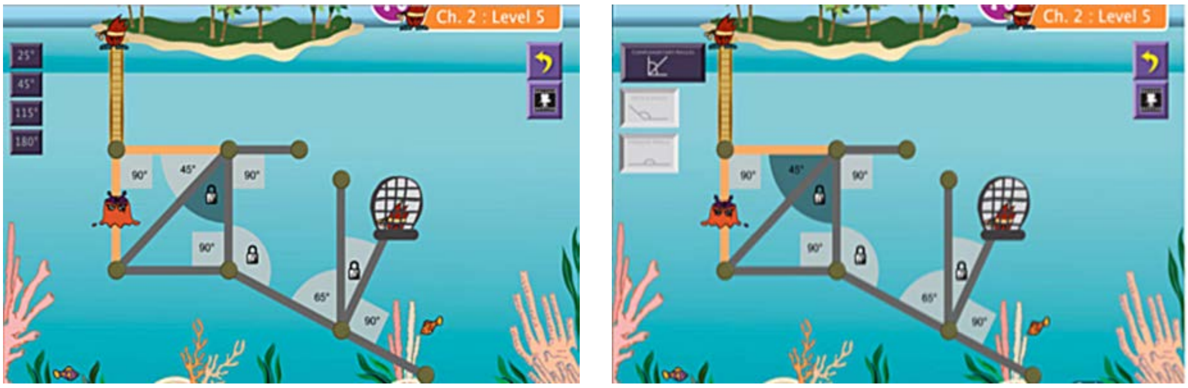


**Figure 1. Arithmetic version (left) and Conceptual version (right) on the same game level**

### *Learning Measures*

A pretest-intervention-posttest design was used to measure the effect of different learning mechanics on student learning (Dugard & Todman, 1995). To test both prior knowledge and post-intervention knowledge, a 21-item paper-based test was designed by the researchers, containing three sets of questions, which covered the topics on angles introduced in the game. The pre- and post-tests both assessed the participants' knowledge of angle types (Set 1) and angles within triangles (Set 2).

### *Measures of Subjective Game Experiences*

Motivation was measured using in-game questions presented at the end of each chapter. After each chapter, students answered four questions about their experience before being able to move on. Using a five point Likert scale (1 ="Not at All" and 5 = "Very Much") students were asked about their subjective experiences in the game. These questions were: 1) How much fun was this part of the game? (enjoyment), 2) How difficult was this part of the game? (challenge), 3) How much do you want to continue playing this game? (engagement), 4) How interesting was this part of the game? (situational interest). Answers to these questions were required in order to proceed to the next chapter of the game. These answers recorded in local log files.

## Results

## Learning (Pre-Posttest analysis)

A paired samples *t*-test across groups revealed a significant difference for both Set 1 questions ($t = 6.146$, $p < 0.001$) and Set 2 questions ($t = 2.72$, $p < 0.01$) in positive learning outcome from pre- to post-test. Next, we examined learning outcomes by group using an analysis of covariance (ANCOVA) to examine AV vs. CV achievement after controlling for the differences between groups in their pre-tests (Table 1). ANCOVA was required because an initial, independent samples *t*-test comparing the pre-test scores of CV and AV in these two categories showed statistically significant differences between groups for each question set ($M_{AV} = 10.04$, $t = 6.52$, $M_{CV} = 7.42$, $p < 0.001$; $M_{AV} = 2.13$, $M_{CV} = 1.37$, $t = 3.19$, $p < 0.01$).

Results indicate that, after controlling for the pre-test scores, there is a statistically significant difference between groups in their mathematics achievement for Set 1 questions, $F(1, 179) = 12.05$, $p < .001$, *partial* $\eta^2 = .06$ with observed power of .93. Similar results held for Set 2. Results indicate that after controlling for the pre-test scores, there is a statistically significant difference between groups in their mathematics achievement for Set 2, $F(1, 179) = 5.54$, $p < .05$, *partial* $\eta^2 = .03$ with observed power of .67.

| | | Unadjusted | | | | Adjusted | | | |
|---|---|---|---|---|---|---|---|---|---|
| | $N$ | $M_{SET1}$ | $SD_{SET1}$ | $M_{SET2}$ | $SD_{SET2}$ | $M_{SET1}$ | $SE_{SET1}$ | $M_{SET2}$ | $SE_{SET2}$ |
| AV | 100 | 11.12 | 2.61 | 2.53 | 1.55 | 10.45 | 0.22 | 2.35 | 0.13 |
| CV | 83 | 8.28 | 2.73 | 1.59 | 1.62 | 9.30 | 0.25 | 1.90 | 0.14 |

**Table 1. Adjusted and Unadjusted group means and variability for post-test scores using pre-test scores as a Covariate**

## Subjective Experiences

For the motivation related measures, we conducted a MANOVA to measure change over time and the differences between groups. Because approximately 75% of participants did not reach Chapter 4 of the game in the allotted time frame, only subjective experience reports between Chapters 1 -3 were analyzed.

The number of chapters students completed affected their subjective experiences statistically significantly. A doubly multivariate analysis was conducted to examine possible differences between the AV and CV in the amount of change in participants' reports on the subjective experience measures. Assumptions for the test were met (Stevens, 2002). Statistically significant multivatiate effects were found for the main effects of group, $F(4, 105) = 3.22$, $p < 0.05$, partial $\eta^2 = 0.11$ (see Tables 2, 3, 4, 5 for details) and for the chapters, $F(8, 101) = 23.93$, $p < 0.001$, partial $\eta^2 = 0.66$, but not for the interaction between groups and the chapters. This lack of interaction means that the difference between the groups on the linear combination of the four dependent variables is not statistically significantly different from Chapter 1 to Chapter 3. Follow-up ANOVAs reveal that engagement ($F(2, 216) = 3.42$, $p < 0.05$, partial $\eta^2 = 0.03$), interest ($F(2, 216) = 2.08$, $p < 0.05$, partial $\eta^2 = 0.03$), and challenge ($F(1.87, 202.00) = 121.36$, $p < 0.001$, partial $\eta^2 = 0.53$) changed statistically significantly over 3 Chapters. However, the amounts of change in the outcomes were not statistically significantly different for AV vs. CV groups.

### *Enjoyment*

CV participants reported statistically significantly higher levels of enjoyment than AV after each chapter (see Table 2).

| | Chapter 1 | | | | Chapter 2 | | | | Chapter 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* |
| CV | 4.37 | 0.94 | 3.40 | 0.001 | 4.01 | 1.26 | 2.21 | 0.028 | 4.27 | 1.13 | 2.44 | |
| AV | 3.76 | 1.24 | | | 3.58 | 1.40 | | | 3.72 | 1.26 | | |

**Table 2. Statistics of the differences between groups on game enjoyment over three chapters.**

### *Challenge*

Although CV participants reported higher levels of challenge than AV participants after the first chapter, a statistically significant difference did not occur after chapters two and three (see Table 3), although both groups' perceptions of challenge as shown in their mean scores rose as they progressed through the game.

| | Chapter 1 | | | | Chapter 2 | | | | Chapter 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* |
| CV | 2.01 | 1.14 | 2.98 | 0.003 | 3.15 | 1.23 | 1.01 | 0.31 | 3.44 | 1.31 | 0.91 | 0.36 |
| AV | 1.57 | 0.96 | | | 2.96 | 1.25 | | | 3.23 | 1.09 | | |

**Table 3. Statistics of the differences between groups on felt challenge over three chapters.**

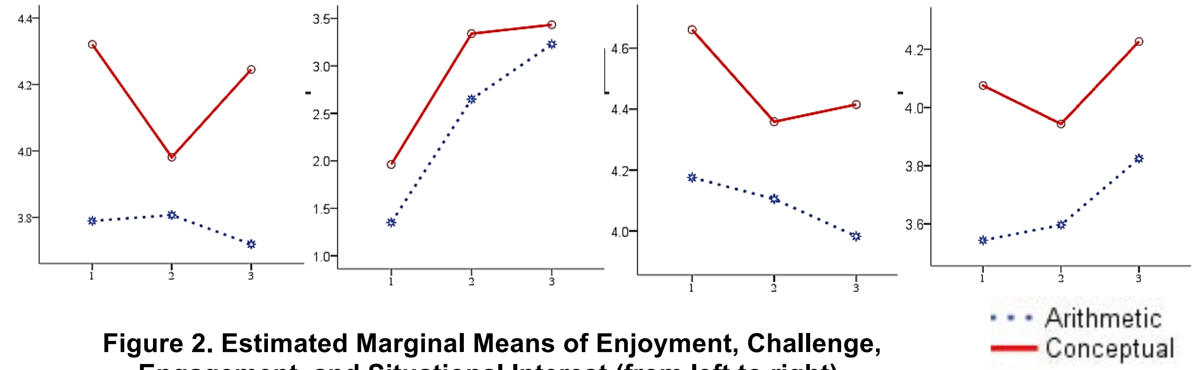


**Figure 2. Estimated Marginal Means of Enjoyment, Challenge, Engagement, and Situational Interest (from left to right).**

### *Engagement*

Reported engagement was high for both groups. However, CV participants consistently wanted to continue playing more than AV participants did (see Figure 2 and Table 4).

| | Chapter 1 | | | | Chapter 2 | | | | Chapter 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* |
| CV | 4.61 | 0.88 | 3.65 | 0.001 | 4.39 | 1.11 | 3.29 | 0.001 | 4.44 | 1.01 | 2.24 | |
| AV | 4.08 | 1.19 | | | 3.81 | 1.33 | | | 3.98 | 1.13 | | |

**Table 4. Statistics of the differences between groups on player engagement over three chapters.**

### *Situational Interest*

There were statistically significant differences between groups in reported situational interests after the first and second chapters, but not after chapter three, even though both CV and AV participants reported their highest level of situational interest after the third chapter (see Table 5).

| | Chapter 1 | | | | Chapter 2 | | | | Chapter 3 | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* | *M* | *SD* | *t* | *p* |
| CV | 4.10 | 1.06 | 2.86 | 0.005 | 3.94 | 1.36 | 2.44 | 0.016 | 4.24 | 1.07 | 1.93 | |
| AV | 3.63 | 1.25 | | | 3.47 | 1.26 | | | 4.30 | 1.18 | | |

**Table 5. Reported situational interest over three chapters and statistics of the differences between groups**

## Discussion

This study examined potential differences in learning and engagement motivation across two versions (conceptual and arithmetic) of the same game, implemented using different *learning* mechanics while holding *game* mechanics constant. Game version had a statistically significant impact on students' learning gains, thus results indicate that games with the same game mechanics and differing learning mechanics can impact outcomes and players' subjective experiences. An interesting result of this study is that even though students in the CV enjoyed the game more, AG participants' achievement from pretest to posttest was higher.

Students in the CV reported higher engagement, enjoyment and situational interest toward the game than students in the AV. Although the CV group indicated a higher challenge perception than AV for the first chapter of the game, this difference disappeared in the following chapters. Positive experiences, as reported by students in the CV group, dropped at the end of the 2nd Chapter, which is puzzling. Future studies may consider conducting short interviews with participants after they complete the game session to investigate further the possible reasons for reported changes in their perceived experience.

In addition to self-report data, future studies will also examine the effect of in-game player interaction time. We can see from Tables 2, 4, 5 that after finishing Chapter 3, students reported an increase in their subjective positive experiences. It is possible that as they play longer, and advance farther in a game, they enjoy it more.

Given game designers' ability to "design the structures and contexts in which play takes place" (Salen & Zimmerman, 2004, p. 67), this research has implications for educators and game designers. Findings call for careful consideration of learning mechanics to maximize players' learning and motivation, inform understanding of the potential influence of different learning mechanics in educational games, and suggest the importance of considering how different learning mechanics may be used in different stages of learning.

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