

How Challenge Can Affect Concept Acquisition in Game Based Learning

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Abstract

This study examined the role of challenge level in acquiring new concepts within an action-oriented educational game. Thirty-six subjects from non-technical backgrounds played the action-oriented, first person perspective, commercial video game Half Life 2. Our team “modded” the game to use an original world map, and added a mechanic in which buttons and other objects in the game world could be shot with the player’s weapon and, in so doing, activate switches and puzzles. The game required players to solve a series of puzzles based on Boolean logic, presented in the nomenclature of programming languages. Subjects were randomly assigned to one of two groups: high-challenge and low-challenge. To advance within the game, players were required to fight through waves of enemies, and then solve a Boolean logic puzzle at choke points within the game map. Subjects in the high-challenge group were required to manually work through the puzzles through trial and error, while subjects in the low-challenge group were presented the puzzle in its solved state. The independent variable was therefore the degree of challenge required to resolve a choke point and advance. To assess concept acquisition, both groups were administered pre- and post-game multiple-choice quizzes that contained several Boolean logic problems. Pre- and post-game quiz scores were compared to determine if a) there was any improvement between pre and post, and b) challenge level was a factor in predicting performance. Analysis by two-way ANOVA revealed no significant performance difference in quiz scores for either the high- or low-challenge group. Our findings should be regarded as incremental rather than conclusive, as it is unclear whether a floor effect was observed -- an indication the test material was too difficult for both levels-- or if, in fact, there

was no difference between the two groups. The authors recommend further study in a less technically challenging problem domain wherein test scores demonstrate more variance.

Introduction

Boolean logic is a form of algebraic reasoning that was developed by George Boole in 1854 [1], and provides the conceptual foundation for modern digital computing systems. Understanding the basics of Boolean logic and how it is implemented in computer programming languages is essential knowledge for any technical domain.

In his seminal text, Digital Game Based Learning, Prensky [2] describes the educational discipline of game-based learning (GBL) simply as the combination of games and learning. A great deal of research has gone into determining the factors that make GBL most effective, and under what circumstances. Chiu et al. [3] conducted a review of the existing literature of GBL in the context of language learning and discovered net positive learning outcomes. Telner et al. [4] conducted a randomized trial to compare learning outcomes in the domain of continuing medical education. Health care professionals were either provided the traditional case-based material or a game-based intervention. The study revealed no differences in educational efficacy, but a clear learner preference in favor of the GBL approach. Weng, Tseng & Lee [5] developed and tested a GBL approach to teaching Boolean logic, in which learners manipulated the rules driving an implementation of the arcade game, Pac-Man. They reported both increased learner affinity for the game, as well as improved learning outcomes. Furthermore, learners who used the game were better able to generalize what they were taught in the game to new contexts.

Despite these encouraging developments in GBL, much work remains to determine optimal delivery factors for GBL. The roles of lesson and learner characteristics, style of game, input devices and many other factors that affect the efficacy of GBL, remain inadequately understood.

Educational video games are designed to provide an engaging entertainment experience, while also teaching the player a particular lesson or concept. The extent to which a game gravitates to one pole or another can be categorized along a continuum between lesson and experience [6]; educational game designers seek to target their game to a particular point on this continuum. What remains unclear is if the type of lesson or, more specifically, the difficulty of the lesson, is a factor in determining the appropriate experiential focus of an educational game. It is not presently known if teaching a challenging, unfamiliar topic to a player/learner imposes different design requirements.

This study examines the role of the level of concept challenge in GBL. Learners were presented with an action-oriented, “first-person shooter” style video game that presented a series of Boolean logic puzzles. Group 1 (High Challenge) subjects were presented the puzzles in an unsolved state and were required to work out the solutions themselves; Group 2 (Low Challenge) subjects were presented the same puzzles in their solved state. To determine if differential learning effects occurred, pre and post-game Boolean logic tests were administered.

Materials and Methods

Research Questions

The research questions driving this study were as follows:

- 1) Did players in the High Challenge (HC)

condition score differently on the pre and post-game quizzes from players under the Low Challenge (LC) condition?

- 2) Was reported enjoyment of the game associated with differences in Challenge (Δ)?
- 3) Was gender associated with challenge (Δ)?
- 4) Do participants find the game enjoyable (Likert scale, 1-10 with 10 being greatest enjoyment)?

Study Participants

Subjects were recruited from an English composition class, due to the decreased likelihood they would be well versed in the syntactical conventions of Boolean logic within computer programming languages. Subject assignment to HC/LC groups was balanced across gender, but was otherwise random. Gender distribution was as follows: HC: 7 females, 11 males, LC: 9 females, 9 males. This study was conducted in full compliance with all IRB rules and regulations.

System Design and Implementation

The game used in this study was a customized version of Half Life 2 by Valve Software and is a “first person shooter” experience that is controlled by the player’s mouse and keyboard. Our team used the game modification tools included in the game to construct a new game world designed with chokepoints that blocked player’s progress through the world. During the game, the player controls an avatar that must traverse the game’s three-dimensional virtual world. The world is populated by enemy soldiers who are trying to shoot the player’s avatar and keep it from reaching the world’s exit. Along the way, players are presented with Boolean logic puzzles, which they must solve by shooting appropriate buttons and targets. The player controls the direction of his or her view of the world using the mouse, and shoots using the left mouse button. The player uses the keyboard to move her or his avatar through the world.

The Game

The game is set in a military complex incorporating both indoor and outdoor areas (Figure 1), and is populated by soldiers who attempt to capture and kill the player's avatar. The player is trapped in any of three discrete zones and can only escape a given zone when a puzzle is solved. The player's goal is simply to escape the complex alive.

Each puzzle is a Boolean logic argument in the rough form of *term sign term = true/false*. The argument is missing a term or a sign; players provide either the missing term or the missing sign in order to make the entire argument valid. The game contains three different puzzles, each more complex than the last. The puzzles use syntactic conventions akin to those in most modern computer programming languages (e.g. `&&`, `//`, `<`, `>`, `==`). As a selection mechanism,

the player shoots a target icon mounted on the wall, which toggles a new term into view (Figure 2). The player shoots the target, then scrolls down the list of possible terms in much the same way one uses a slider bar. After selecting a term or sign, the player shoots the "Enter" button to register the answer.

When the player builds a valid sequence, a door opens and allows access to the next section of the complex. Further, the player is rewarded with a more powerful weapon and a health kit to remedy any previously incurred damage. In the event the player constructs an invalid sequence, a squad of fresh enemy soldiers arrives and attacks the player. In terms of overall player experience, the primary dimensions of the game include a combination of solving logic puzzles, engaging in intense, action-oriented gaming, and attempting to escape the complex within the allotted timeframe.



Figure 1. Map of the game world: a large military complex in which the player finds him or herself trapped.



Figure 2. Players make selections within the game by shooting wall-mounted icons. Shooting the blank squares causes new terms to appear. The player's goal is to assemble a valid logical argument string in the form of a sequence of Boolean logic operators.

Learning Objectives

Three Boolean logic puzzles were created and were presented such that problem complexity scaled up as the player got farther into the game. The in-game puzzles were structured as logical statements in the form of:

$$X \underline{\quad} Y$$

The underline represents where the player will provide a substitute Boolean logic symbol – in programming vernacular – that will make the particular statement resolve correctly. The targets act something like a multiple choice assessment mechanism.

The learning objectives are as follows:

- 1) Student will demonstrate the use of equality and inequality operators to complete a logical sentence.

- 2) Students will demonstrate the use of logical phrases: AND, OR, and NOT to complete a logical sentence.

While it is important that the player learn the concepts, we were most interested in seeing if the level of challenge had any tangible effect on player learning.

Evaluation

The study was constructed using a pre-test/post-test design. Subjects were randomly assigned to one of two groups. Group 1 (High Challenge, HC) was the high-challenge group and was required to actively solve Boolean logic puzzles by interacting with objects in the game world. Group 2 (Low Challenge, LC) was the low-challenge control group and was presented with a solution to the puzzle, pre-solved. Players in the LC group only interacted with the puzzle to the extent that they had to shoot the "Enter" button when ready to proceed to the game's next zone. The countdown timer (Figure 3) was in



Figure 3. The in-game countdown timer continuously counted down to zero in order to compel players to continue moving forward through the game world.

place for both groups, in order to impose an element to the game experience that would help compel the player forward through the game world.

Assessment

Learning was measured using a 14-question quiz that was administered before and after the game. The quiz presented Boolean logic questions similar to those observed within the game. To control for test/retest effects, questions in the pre and post-games tests were paired such that they represented the same concept, but used different parameters for each test. An example question is presented below.

Pre-Test Question: What is the logical outcome of the statement: $6 > 9$? True or False?

Post-Test Question: What is the logical outcome of the statement: $5 > 8$? True or False?

Subjects were also asked the following non-educational related questions:

- Rate how much fun you thought the game was (1 being least, 10 being most).
- What is your gender?

Results

To address the study's research questions, the collected data were analyzed along the following dimensions:

- 1) Difference in pre and post-game quiz scores (Δ), compared versus the high challenge (HC) and low challenge (LC) groups,
- 2) Correlation between reported enjoyment of the game (GE) and the difference in quiz performance between the pre and post-game quizzes (Δ),
- 3) Correlation between gender (Δ) and the difference in quiz performance between the pre and post-game quizzes (Δ).
- 4) Mean level of reported enjoyment.

A two-way ANOVA ($\alpha=.05$, $N=18$, $\mu=-3.388$, $\sigma=16.5$) was conducted to examine differences between the pre and post-tests in the HC group.

As $p=.395$, no difference was detected between the pre and post-game scores of subjects in the HC group. Subjects in the HC group's scores neither improved nor decreased between quizzes.

A two-way ANOVA ($\alpha=.05$, $N=18$, $\mu=-6.0$, $\sigma=17.62$) was conducted to examine differences between the pre and post-game quiz scores in the LC group. As $p=.166$, no difference was detected between the pre and post-game scores of subjects in the LC group. Subjects in the LC group's scores neither improved nor decreased between quizzes.

A two-way ANOVA ($\alpha=.05$, $N=36$, $\mu=-4.694$, $\sigma=16.87$) was conducted to examine differences between the pre and post-tests in the combined HC/LC group. As $p=.955$, no difference was detected between the pre and post-game scores of subjects in the combined group. Subjects in the combined group's scores neither improved nor decreased between quizzes.

A test was conducted to determine whether Enjoyment was associated with Challenge Δ scores. A Pearson product-moment correlation R was calculated separately for positive and negative Δ scores. The R for positive Δ scores was .26, and the R for negative Δ scores was .20. Based on these observations, there is no evidence to suggest that game enjoyment could predict the Δ between the pre and post-game quizzes.

A comparison was conducted of Gender versus Challenge Δ scores. A two-tailed t -test was conducted ($\alpha=.05$, $N=36$) resulting in an observed $p=.955$ indicating no association between gender and Δ scores.

Lastly, mean levels of enjoyment, as per Likert responses (1-10, with 10 being most enjoyable) were recorded. Participants in the HC group reported a mean enjoyment rating of 8.0; participants in the LC group reported a mean enjoyment of 7.0.

Discussion

No statistically significant effects were observed relating to level of challenge, enjoyment, or gender. We cannot say with confidence that our approach revealed differential effects on learning effectiveness as influenced by the effect of challenge level. It is presently unclear as to why significant effect sizes were not observed. However, subjects reported they found the game experience enjoyable and would be interested in further attempts to study Boolean logic via a game-based learning approach. Our study revealed a number of dimensions that should be relevant to not only developers of mathematics and engineering-oriented games, but to any game-based learning project. We recommend more research along the following lines to more precisely clarify any mitigating factors.

Acclimatization to New Concepts

Participants seemed to like the game quite a lot and were willing (but not allowed) to play it beyond the allotted time. This observation is encouraging, as it suggests the game could serve as a vehicle to introduce new or complex concepts to students in a way that entices them to spend more time and enjoy themselves more while learning. As many other researchers have observed [7, 8], educational games seem to be effective vehicles for engaging student interest.

Challenge Level Too High

It seems quite possible that the topic of Boolean logic, combined with its dense nomenclature, could have been too alien to our particular audience of English majors. A floor effect may have occurred, in which students required more prerequisite priming in order to absorb the in-game lessons. We recommend either tuning the content such that the students are ready to absorb the lesson, or provide more time with the game so students can receive more instruction.

Gameplay Time

Subjects were allotted fifteen minutes to play the game and, therefore, absorb the game's Boolean logic lessons. As Weinschenk [9] observed, learning through repetition, rather than recollection tends to yield superior results. We suggest that longer or repeated playing times would be much more likely to yield more pronounced effect sizes.

Out-of-Game Learning Assessments

The issue of transference across media was likely considerable. Though the justification for using a paper-based assessment was rooted in a desire to improve generalizability of the results, we nonetheless feel this issue may have unintentionally introduced a co-varying factor that diluted our observed effect sizes. We recommend that any future work based upon our findings attempts to provide pre and post-game assessments that more closely mirror the form and format of the quizzes used within the game itself.

Quizzes

Pretest

Please attempt to answer the questions to the best of your ability. Note, do not consider the code syntax – just assume the syntax is correct.

1. What is the value of x after the following statement is performed?

$$x = 7 + 3 * 6 / 2 - 1$$

- a. 60
- b. 29
- c. 23
- d. 15

2. What will print when each of the following statements is executed?

(assume $x = 2$ and $y = 3$)

if $x > y$

Print "A"

Else

Print "B"

- a. "B"
- b. "A"
- c. Nothing is printed
- d. Both "A" and "B" are print

3. What will print when each of the following statements is executed?

(assume $x = 2$ and $y = 3$)

- a. "AB"
- b. Nothing is printed
- c. "CB"
- d. Both "CB" and "AB" are printed

4. What will be the result of the following statements? (T is true, F is false, && is AND, || is OR)

T && F

- a. False
- b. True

5. What will be the result of the following statements? (T is true, F is false, && is AND, || is OR)

T || F

- a. False
- b. True

6. What is the logical outcome of the following statement?

$6 > 9$

- a. True
- b. False

7. What is the logical outcome of the following statement? (T is true, F is false, && is AND, || is OR, ! is NOT)

!($3 > 2$) && (T || F)

- a. True
- b. False

8. What value will be printed?

```
int i = 0;
while (i <- 10) {
    if (i == 7)
        break;
    else
        i = i + 1;
}
Print i;
```

- a. 0
- b. 1
- c. 7
- d. 10

9. What will be the result of the following statements? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
!T || F
```

- a. True
- b. False

10. Which logical operator inserted between the two arguments would make this **true**? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
(!T ____ !F)
```

- a. &&
- b. ||
- c. !
- d. None of the above

11. Which logical operator inserted between the two arguments would make this **true**? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
(F && F) _____ (T || F)
```

- a. !
- b. &&
- c. ||
- d. None of the above

12. Which logical operators would make this **true**? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
(8 < 2) _____ (T && F)
```

- a. &&
- b. !
- c. ||
- d. None of the above

13. Which series of logical operators would this **true**? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
(_____ || _____) && !(_____ && _____)
```

- a. F F T F
- b. F T T T
- c. F T F F
- d. T T T T

14. Which series of logical arguments would make this false? (T is true, F is false, && is AND, || is OR, ! is NOT)

```
(T _____ F) _____ _____ (10 _____ 9)
```

- a. || || ! <
- b. || && ! <
- c. || || ! >
- d. || && ! >

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Author Disclosure Statement

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