Handbook of Research on Effective Electronic Gaming in Education

Richard E. Ferdig
University of Florida, USA

Volume I

Information Science REFERENCE
INFORMATION SCIENCE REFERENCE
Hershey · New York

Director of Editorial Content:	Kristin Klinger
Managing Development Editor:	Kristin M. Roth
Senior Managing Editor:	Jennifer Neidig
Managing Editor:	Jamie Snavely
Assistant Managing Editor:	Carole Coulson
Copy Editor:	Maria Boyer, Amanda Appicello
Typesetter:	Carole Coulson
Cover Design:	Lisa Tosheff
Printed at:	Yurchak Printing Inc.

Published in the United States of America by
Information Science Reference (an imprint of IGI Global)
701 E. Chocolate Avenue, Suite 200
Hershey PA 17033
Tel: 717-533-8845
Fax: 717-533-8661
E-mail: cust@igi-global.com
Web site: http://www.igi-global.com

and in the United Kingdom by
Information Science Reference (an imprint of IGI Global)
3 Henrietta Street
Covent Garden
London WC2E 8LU
Tel: 44 20 7240 0856
Fax: 44 20 7379 0609
Web site: http://www.eurospanbookstore.com

Handbook of research on effective electronic gaming in education / Richard E. Ferdig, editor.

p. cm.

Summary: "This book presents a framework for understanding games for educational purposes while providing a broader sense of current related research. This creative and advanced title is a must-have for those interested in expanding their knowledge of this exciting field of electronic gaming"--Provided by publisher.

Includes bibliographical references.

ISBN 978-1-59904-808-6 (hardcover) -- ISBN 978-1-59904-811-6 (e-book)

1. Simulation games in education--Handbooks, manuals, etc. 2. Electronic games--Handbooks, manuals, etc. I. Ferdig, Richard E. (Richard Eugene)

LB1029.S53H36 2008

371.39'7--dc22

2007052787

British Cataloguing in Publication Data
A Cataloguing in Publication record for this book is available from the British Library.

Chapter XVI
COTS Computer Game Effectiveness

Carol Luckhardt Redfield
St. Mary's University, USA

Diane L. Gaither
Southwest Research Institute, USA

Neil M. Redfield
John Jay Science and Engineering Academy, USA

ABSTRACT

This chapter looks at the effectiveness of commercially available educational computer games. It defines what a game is from game theory and what an intelligent tutoring system is, suggests some concepts from these areas to use for game development, and reflects on some surveys of commercial off-the-shelf (COTS) educational software, including computer games. Two effectiveness studies conducted at John Jay High School, and the results of the studies are presented on the educational computer game Math Blaster Algebra. *One of the studies showed a positive learning increase from using* Math Blaster Algebra. *Both studies showed no negative impacts on scores and grades with more time playing the game. With lessons learned from game theory, the intelligent computer-based training field, and these effectiveness studies, educational computer gaming can continue to grow, be effective, and be accepted into educational systems.*

INTRODUCTION

For centuries, people have played games. Some of the games have been educational. In recent history, games have been made available electronically, on separate handheld devices and on computers, either on standalone computers, networked machines, or over the Internet.

There have been a number of books about computer games and learning, including those by Gee (2003), Michael and Chen (2006), and Pensky (2001), but no effectiveness studies have been made available to the public on these commercial off-the-shelf educational computer games. Many educational software title materials say that they help in learning, but do not show any empirical tests.

This book discusses the effectiveness of educational electronic games. The objective of this chapter is to present results of some surveys of commercial off-the-shelf (COTS) educational computer games, to report on effectiveness studies on one of the COTS games, and to discuss a possibility for improving the effectiveness of learning for students who play these games. The effectiveness study procedures are presented of *Math Blaster Algebra* with some Algebra 1 students at John Jay High School. The statistically significant results are shown in detail. Hopefully, others will become more interested in making good games and performing effectiveness studies on games by improving on the methods and procedures presented here.

BACKGROUND

Every game has at least one player, often two, and even more. Single-player games are often called puzzles. Every game has a goal or outcome that a player or set of players is working to achieve. Sometimes the goal is just to score points or collect objects, and sometimes when the goal is met, the game is over. Every game has rules that the players play by, even if the rules are not well defined or change during game play. In every game, players are making moves where they select actions from a set of possible actions. The moves may be turn-based or simultaneous with other players. In addition to these characteristics of a game, every educational game has an objective to teach or practice some kind of knowledge or skill.

The following sections outline some background areas of work that may be useful in the development of educational computer games so that the games can be more effective for teaching and learning. Some concepts are presented from game theory and intelligent tutoring systems that include concepts from artificial intelligence and instructional design theory. These two topics are referred to in the last sections of this chapter to potentially improve the learning effectiveness of educational computer games. There is also a summary of surveys that have been done on commercially available educational software that were used to help select *Math Blaster Algebra* for the studies.

GAME THEORY

The study of games began to be formalized with the mathematical field of game theory (Osborne & Rubinstein, 1994). Players in a game are contenders that can be human, machine, nature, or other entities. The players control some piece of a situation in a game. Games with many players are called n-person or multiplayer. A strategy is a set of rules that a player uses to play the game. A move by a player is given by the player's strategy. A move determines the next state of the game. Players are contending for various payoffs that are the results or consequences for the players at the end of the game. A player may get a reward or have to give up something.

One way to define a game is by the rules of the game, including the relationships between players, who moves when, what information is available, alternatives available to a player, and the outcomes of each sequence of choices. The extended form of a game from game theory specifies these four things:

- Initial state of the game
- Admissible moves from one state to another
- Terminal or end of the game states
- Payoffs to the players at the end of the game

All the possible strategies for a player *i* are represented by a set, S_i. The normal form of a game is a set of all the strategy sets for each player and the payoff functions for each of the players P_i that map a strategy for each of the players to the payoff for the player *i*:

$$\{S_1, \ldots, S_n; P_1, \ldots, P_n\}$$

A common representation for the play of a game is a game tree. The initial state of the game is represented at the root node. The first moves the first player can make are represented by the children of the root node, and children of those nodes contain the new states of the game for the next player to make a move. Each successive level of children represents the possible moves of the next player and the resulting states of the game, until the end of the game. The leaf or terminal nodes are the possible places where the game ends.

In general, game theory tries to find the best or likely end-result as a solution of a game. The solution often depends on the type of game. A zero-sum game is one that has the sum of the payoffs at the end of the game equal to zero. A constant-sum game is a one where the sum of the payoffs is always a specific constant amount at the end of the game. A perfect information game is one where all the players know all the other players' actions in the game. A cooperative game is one where players are allowed to form coalitions to work together. Otherwise, the game is non-cooperative. Other game theory classifications include finite or infinite, continuous, probabilistic, differential, Markov, quota, non-atomic, compound, and stochastic. Depending on the classification of a game, different game theoretic solutions apply to the game. The game solutions infer ways to play the game, but game theory solutions are developed from the view of the entire game having been played out.

Most educational games have one or two players where the computer may be considered a player. The educational computer games we see are also perfect information, constant-sum, and non-cooperative games. Game theory solutions for these kinds of games are about finding a saddle point where the payoffs are the best for both players given the competitive nature of the game. Multiplayer game solutions, of a similar type of game otherwise, find an equilibrium point where any one player can do no better by selecting a different strategy while all the other players' strategies stay the same. Other kinds of game theoretic solutions include the Bargaining Set, Core, Kernel, Shapley Value, and Stable Set. When educational computer games have the characteristics of perfect information, constant-sum, and non-cooperative, our games could direct the student toward a saddle or equilibrium point in an interesting and entertaining way. When a game is cooperative, a player will tend to do better when playing with as large a coalition of players that the player can be a part of (Luckhardt, 1989).

Intelligent Tutoring Systems

Educational games have been developed that are considered tutors to teach skills and concepts similar to having a person tutor a student. Some computer-based tutoring systems just present a concept or set of concepts, and then the student applies the concept in a testing-type situation that can be part of a game. There are also tutoring games that present material based on how well a student has performed. Presenting material based on a student's history provides a more personalized approach to the instruction. When there is a model of the student's behavior and knowledge that is used by an instructional module to present material to the student, the software is called an intelligent tutoring system (ITS) (Burns, Parlett, & Redfield, 1991). It has been shown that a computer-based tutoring system can be modified to perform as an intelligent tutoring system (Redfield, 1995). An ITS has a student model, instructional module, an interface module to present the information, and an expert model that contains the material or knowledge to be presented. Intelligent tutoring systems are a combination of artificial intelligence, learning theory, and instructional theory. Instructional design theory is based on Gagné's events of instruction (Gagné, Briggs & Wager, 1992) that include: gain attention, inform objectives, stimulate recall, present content, provide guidance, elicit performance, provide feedback, assess performance, and enhance retention. Many of these ITSs have been shown to be effective including Stat Lady, which was created at Brooks Air Force Base to teach statistics; also, many tutors created with the XAIDA authoring tool (Murray, Blessing, & Ainsworth, 2003).

Some of the ITSs that are also games have been shown to be effective. These games were created and tested in research laboratories, and the study results were not always available to the general public. One study showed that an ITSs did not make any more significant difference in learning than just spending more time on the task of learning the subject in other formats (Hall, 1987). A few of these intelligent tutoring system games have been sold to school systems such as *ISIS* from TutorTek that teaches the scientific method (Steuck & Meyer, 2003) and *Cognitive Tutor Algebra 1* by Carnegie Learning (2007).

COTS Educational Computer Games

Commercial off-the-shelf computer games have been available since the first personal computers could be purchased in the early 1980s. These games started out having the purpose of entertainment. People realized that games could be used to teach subject matter in a way that was different from the classroom setting and perhaps effective in other ways. Thus, "edutainment" and later "serious games" have been the buzzwords.

When personal computers became less expensive and easier to use with graphical user interfaces, games for both entertainment and learning became more available. Families, including children, found that having a computer in the home was ideal for many purposes. Computers started to become more readily available for use in schools. Educators found that computers could be used as tools to teach students.

A few surveys have been done on existing educational software titles that included computer games. A survey done in 1998 (Redfield, 1999) found around 200 titles for pre-kindergarten to adult. A survey in 2000 (Redfield, 2000) found over 200 titles for just the elementary grades. The surveys considered course content topics from a number of state and national standards and included business, computer literacy, economics, English language arts, fine arts, geography, health, history, mathematics, physical education, Spanish, science, U.S. history, and vocational education. These surveys found that no matter what high-level topic you select, there is some software title that can be purchased that will contain some of the material of that topic. Many of the titles from these two surveys were games or had a game component.

In 2005, a survey was performed to gather just educational computer games. A computer game was considered educational if the game documentation included learning about an area or if the game has been used in a learning situation. That survey resulted in a database of over 1,000 titles (Gaither & Redfield, 2006). The data from this survey at *www.wingz2fly.com/GameSurvey* is being updated regularly by graduate students at St. Mary's University in San Antonio, Texas. There is also a database for educational software that can be used to search for games at *http://www-ed.fnal.gov/espg.* This database contains 127 computer games that are noted as educational (Educational Software Preview Guide Consortium, 2007). Companies that have produced many educational computer games include Funschool, Knowledge Adventure, The Learning Company/Riverdeep, Scholastic/Tom Snyder Productions, and Sunburst Technology.

COTS GAME EFFECTIVENESS

Since many COTS educational computer games say that they do teach something or improve learning, it would be beneficial to know exactly what games are available to the public and to note if there is any data to support what the games are purporting. It would also be useful if the games were in an organized system that could be searched to find out what is available and to find games with a specific content or at a certain age or grade level. The survey by Gaither and Redfield (2006) made available on the Internet a searchable database of educational computer games.

In the 2005 survey, the subjects taught to the elementary-level students filled the spectrum of educational courseware. Games covering topics from foreign language studies, to science, to typing proficiency were available. The teaching methods that these games utilized varied considerably. Some games were strictly drill and practice, while others used simulations and role-playing. Over 70% of the games in the survey targeted elementary-level students. Approximately 7% of all the games are targeted toward middle school students, and 14% of the games recorded were targeted to high school level and above. There were many more titles in language arts and mathematics at the elementary level, while there were many more titles in science for middle school and high school. This survey noted the lack of educational games available for the upper grade levels. The educational game industry has a wide open market for older students and higher learning courseware.

Table 1 shows a list of some of the COTS educational computer games from the database at *www.wingz2fly.com/GameSurvey.* This list of games shows the games that say they teach mathematics for sixth grade or higher. Each game title can be selected in the table on the Web page to find out detailed information about the game.

The survey did not find any study that measured the effectiveness of any commercial educational game. There have been many studies on the impact and effectiveness of games in education, but none have been made available to COTS educational computer games (Randel, Morris, Wetzel, & Whitehill, 1992). A formal effectiveness study was organized on one educational computer game (Redfield, Gaither, & Redfield, 2007). Algebra was selected as the topic because all high school students must pass Algebra 1, there were students available for the study, and there were a number of existing educational computer games that work with algebra. The Algebra 1 students were made available at John Jay Science and Engineering Academy in San Antonio, Texas, thanks to the principal, Ms. Peggy Greff, and the Algebra 1 teacher, Ms. Monica Gonzales. A number of first-year algebra software titles were considered for the study including the following products:

- Algebra Animator by Riverdeep
- Algebra Concepts by Ventura Educational Systems
- Algebra Stars by Sunburst

Table 1. Computer games for math from www.wingz2fly.com/GameSurvey

Title Math Educational Computer Games	**Publisher**
2xy Algebra Helper	MathRealm
Accelerated Math	Renaissance Learning
Algebra	BestQuest Teaching Systems
Algebra ‘scool: Module 2	BestQuest Teaching Systems
Algebra ‘scool: Module 3	BestQuest Teaching Systems
Algebra Animator	Riverdeep
Algebra Concepts	Ventura Educational Systems
Algebra Stars	Sunburst Technology
ClueFinders-Empire of the Plant People	The Learning Company-Riverdeep
Crocodile Mathematics	Crocodile Clips
Force Addition & Subtraction	Intellectum Plus Incorporated
Freebody	Physics Academic Software
Geometry Concepts	Ventura Educational Systems
Geometry World: Middle Grades Interactive Explorer	MathRealm
Larson’s Intermediate Math Grade 6	Larson’s Learning Inc.
Math Arena Advanced	Sunburst Technology
Math At Work: On the Fly!	CORD Communications
Math At Work: Train Reaction	CORD Communications
Math Blaster	Knowledge Adventure
Math Express	Aces Research Inc.
Mathville: VIP	Ingenuity Works
Measurement in Motion	Learning in Motion
Measurements & Units	Intellectum Plus Incorporated
Mighty Math-Cosmic Geometry	Riverdeep
Mighty Math: Astro Algebra	Riverdeep
Mighty Math: Calculating Crew	Riverdeep
Mind Power Math High School	The Learning Company
Pre-Algebra World	MathRealm
PrimeTime Math: Cliffbound!	Tom Snyder Productions
PrimeTime Math: Emergency!	Tom Snyder Productions
PrimeTime Math: Fire!	Tom Snyder Productions
The Hidden Treasures of Al-Jabr	Sunburst Technology
The Number Devil	Viva Media

- Algebra World by Math Realm
- Math Blaster Algebra by Davidson/Knowledge Adventure
- Mighty Math: Astro Algebra by Riverdeep
- Mind Power Math: High School by The Learning Company/Riverdeep
- Quickstudy Algebra 1 by Selectsoft Publishing
- Windows Algebra by ProOne

The software product for the study had to run on Windows XP, cover much of the Algebra 1 curriculum, be easy to use, stay within a budget, and provide a game environment. The game also needed to meet the requirements for the TEKS (Texas Essential Knowledge and Skills) standardized curriculum (Texas Education Agency, 2007b). *Math Blaster Algebra* was the game best suited for the electronic game effectiveness study since it ran on Windows XP, had a usable user interface, and was still available for purchase ($12-30 per CD, depending on how many are purchased).

Math Blaster Algebra and Studies

Math Blaster Algebra was originally created by Davidson and later purchased by Knowledge Adventure (Wikipedia, 2007). On the game packaging, the publisher of *Math Blaster Algebra* says that the game provides tools to succeed and improve skills in a student's first year of algebra (Knowledge Share, 1998). The skills include

- Using decimals, integers, and rational numbers
- Understanding algebraic expressions and equations
- Working with ratio, proportion, and percent
- Plotting points on a graph
- Factoring polynomials
- Applying the order of operations
- Exploring inequalities and quadratic equations
- Building and solving equations

Math Blaster Algebra takes a player through an animated adventure on a spaceship. The ship called Nomial has broken down from a collision with an asteroid. The goal of the player is to correct the ship operations before the aliens called the Quadraticas find them. The player solves algebraic problems to gather required resources and fix the ship. There are six different rooms (communications, defender, electrical, engine, strategy, and transporter) plus the control center to work and play on the ship. There are six kinds of activities with three different levels. There is context-sensitive help through a robot assistant called Scully. The help includes information and tutorials about the algebraic concepts.

Two learning effectiveness studies were performed on *Math Blaster Algebra* at John Jay Science and Engineering Academy. The purpose of these studies was to determine if *Math Blaster Algebra* is effective in teaching and reinforcing algebra concepts. The first study lasted for a five-week period and was part of a science fair project. After the first study finished, the second study lasted for 16 weeks of the students playing *Math Blaster Algebra.* The studies were approved by the school's Institutional Review Board, which cleared the procedures and ethics of the studies.

The procedures and analysis for the two studies were similar. For the first study, the project was presented to three different ninth-grade Algebra 1 classes to a total of 90 students. Of those 90, 42 volunteered to participate in the first study, 37 volunteered for the second study, and 32 were in both studies. With certain limitations such as availability of a computer, parent approval, and willingness to play the game, the students were separated into two groups. The subject or game group students took a pre-test, played the game at their homes in addition to any class work they received, and took a post-test. The control group

Table 2. First study test scores per student

Game Group	Pre-Test				Post-Test			
Student Number	*Number Attempted*	*Number Correct*	*Number Incorrect*	***Score***	*Number Attempted*	*Number Correct*	*Number Incorrect*	***Score***
2	25	6	19	1.25	24	10	14	6.5
3	12	3	9	0.75	10	4	6	2.5
4	23	12	11	9.25	17	12	5	10.75
5	9	6	3	5.25	7	4	3	3.25
6	12	5	7	3.25	17	7	10	4.5
7	11	3	8	1	19	6	13	2.75
8	11	5	6	3.5	18	7	11	4.25
9	12	5	7	3.25	23	11	12	8
10	25	10	15	6.25	25	13	12	10
11	12	7	5	5.75	12	6	6	4.5
12	18	8	10	5.5	18	7	11	4.25
13	12	7	5	5.75	12	2	10	-0.5
14	17	6	11	3.25	11	7	4	6
15	24	7	17	2.75	11	6	5	4.75
17	7	2	5	0.75	24	6	18	1.5
19	18	9	9	6.75	11	5	6	3.5
20	16	11	5	9.75	25	16	9	13.75
21	21	11	10	8.5	17	10	7	8.25
22	11	2	9	-0.25	3	1	2	0.5
1	15	6	9	3.75	16	4	12	1
16	22	11	11	8.25	5	2	3	1.25
18	12	6	6	4.5	13	4	9	1.75
23	12	7	5	5.75	15	9	6	7.5
24	18	9	9	6.75	23	8	15	4.25
25	8	0	8	-2	12	1	11	-1.75
26	12	9	3	8.25	5	3	2	2.5
27	12	6	6	4.5	10	5	5	3.75
28	10	5	5	3.75	7	3	4	2
29	20	11	9	8.75	17	11	6	9.5
30	21	12	9	9.75	11	4	7	2.25
31	9	3	6	1.5	25	9	16	5
32	25	12	13	8.75	16	12	4	11
33	20	13	7	11.25	21	16	5	14.75
34	13	9	4	8	13	9	4	8
35	15	11	4	10	17	13	4	12

continued on next page

Table 2. Continued

Game Group	Pre-Test				Post-Test			
Student Number	Number Attempted	Number Correct	Number Incorrect	Score	Number Attempted	Number Correct	Number Incorrect	Score
36	15	6	9	3.75	9	3	6	1.5
37	13	6	7	4.25	14	4	10	1.5
38	17	11	6	9.5	12	6	6	4.5
39	20	16	4	15	20	16	4	15
40	11	7	4	6	16	7	9	4.75
41	11	10	1	9.75	16	9	7	7.25
42	7	4	3	3.25	14	9	5	7.75

took a pre-test, continued through the year as normal with the same class work, and took a post-test. Before the beginning of each study period, the students took the pre-test that consisted of a 25 multiple-choice-question test, comprehensive for Algebra 1. This test was created by a certified math teacher and reviewed by three other math professors at St. Mary's University in San Antonio, Texas. The test had to take less than the 50-minute class period to finish and was comprehensive for all of Algebra 1 since *Math Blaster Algebra* includes concepts from all of Algebra 1.

Each game-group student was given a CD of *Math Blaster Algebra* and played the game on a home computer on their own time. Each student recorded the amount of time they spent playing the game. The students were asked to play the game at least two hours per week. After the study periods were completed, each student took a post-test that was the same content as the pre-test. Both the pre-test and the post-test were graded similar to the SAT's grading system, where one point is given for a correct answer, and a quarter of a point is deducted for an incorrect answer. The maximum score is 25 and the minimum is -6.25. The data collected included students' course grade averages; the Texas Assessment of Knowledge and Skills (TAKS), a state-given standardized test in Texas (Texas Education Agency, 2007a) for the second study; and benchmarks (two for the first study and five for the second study) that were taken throughout the year.

The main difference between the two studies was the time the students were able to play *Math Blaster Algebra.* The analyses for both studies were very similar, although the second study had more data available from school-based scores and grades. The significant data is included here so that people who organize future studies can see what worked and hopefully expand and improve on the study.

First Study Data and Results

Tables 2 and 3 show some of the data from the first study, including the individual scores of all students' pre- and post-tests, as well as the number of questions attempted, answered correctly, and answered incorrectly. These tables show only a portion of the data that was collected.

Table 2 contains the overall data for the pre-test and post-test that showed some statistically significant results. The last column shows the number of hours each student played *Math Blaster Algebra.*

Summary data in Table 4 show that the range of pre-test scores was -2 to 19.75, the range of post-test scores was -1.75 to 15, and playing time was

Table 3. First study test scores and time played per student

Subject Number	Pre-Test Score	Post-Test Score	Pre- to Post-Test Difference	Time Played in Hours
2	1.25	6.5	5.25	**7**
3	0.75	2.5	1.75	18.5
4	9.25	10.75	1.5	**52.5**
5	5.25	3.25	-2	**1.5**
6	3.25	4.5	1.25	26.5
7	1	2.75	1.75	**27**
8	3.5	4.25	0.75	10.5
9	3.25	8	4.75	> 2
10	6.25	10	3.75	4.75
11	7.75	4.5	-3.25	**9**
12	5.5	4.25	-1.25	12.75
13	5.75	-0.5	-6.25	1.5
14	3.25	6	2.75	14
15	2.75	4.75	2	44.75
17	0.75	1.5	0.75	**10.5**
19	6.75	3.5	-3.25	15.5
20	9.75	13.75	4	9
21	8.5	8.25	-0.25	**11**
22	-0.25	0.5	0.75	> 2

Table 4. First study summary data

First Study Game Group	Pre-Test Score	Post-Test Score	Pre- to Post-Test Difference	Time Played in Hours
Average	5.887	5.381	-0.506	16.25
Highest	19.75	15	-5.25	52.5
Lowest	-2	-1.75	-3.75	1.5

Table 5. Example t-test results

Pre-Test-Two-Sample Assuming Equal: Variances

	Game group	*Control group*
Mean	4.434210526	7.086956522
Variance	9.450292398	20.78186759
Observations	19	23
Hypothesized Mean Difference	0	
P(T<=t) One-Tail	0.018380204	
P(T<=t) Two-Tail	0.036760408	

1.5 to 52.5 hours. Looking at the pre-test scores, the control group started out at a somewhat higher level of performance than the game group, but not statistically significant.

Much analysis was performed, looking for any kind of significant impact that *Math Blaster* might have had on the students' learning and understanding of algebra. Many statistical tests were performed on the data such as a t-test, both 1-tail and 2-tail. A t-test is a tool for statistical analysis showing if there is a statistical difference in comparing data sets. The t-tests were performed using analytical tools in Microsoft Excel. A few of the t-test results will be shown later. A list of all the t-tests that were performed on the data from the first study is given in Exhibit 1.

Table 5 shows results of one t-test analysis. The analysis shows the comparison of the pre-tests for each of the game and control groups for the first study.

The Mean row shows the average score for all of the game group members and the control group members. In the Observations row, the numbers show the count of for each category. In the first study, there were two students who did not play the game at all, so they were moved to the control group. In the row labeled Hypothesized Mean Difference, since the value is 0, there is no expected

Exhibit 1.

•	Pre-test scores, between groups
•	Post-test scores, between groups
•	Pre-test to post-test difference, between groups
•	Game group pre-test to post-test
•	Control group pre-test to post-test
•	Pre-test correctly answered questions, between groups
•	Pre-test incorrectly answered questions, between groups
•	Post-test correctly answered questions, between groups
•	Post-test incorrectly answered questions, between groups
•	Game group score only using objectives covered
•	Control group score only using objectives covered
•	Game group percent answered correctly of objectives covered
•	Control group percent answered correctly of objectives covered
•	Pre-test to post-test score, difference for objectives covered
•	Pre-test to post-test percent answered correctly, difference for objectives covered
•	Game group 1st grading period to 2nd grading period
•	Control group 1st grading period to 2nd grading period
•	Game group 1st grading period to 3rd grading period progress report
•	Control group 1st grading period to 3rd grading period progress report
•	1st grading period to 3rd grading period progress report difference, between Groups
•	1st grading period averages, between groups
•	2nd grading period averages, between groups
•	3rd grading period progress report averages, between groups
•	Game group 1st grading period to 2nd grading period benchmark
•	Control group 1st grading period to 2nd grading period benchmark
•	Grading period benchmark to 2nd grading period difference, between groups

Table 6. Pre- to post-test difference

T-Test: Two-Sample Assuming Equal Variances

	Game group	*Control group*
Mean	0.776315789	-1.565217391
Variance	8.763157895	16.18873518
Observations	19	23
Hypothesized Mean Difference	0	
P(T<=t) One-Tail	0.020707505	
P(T<=t) Two-Tail	0.04141501	

Table 7. Pre- to post-test differences

T-Test: Two-Sample Assuming Equal Variances:

Relevant Content Scores Pre- to Post-Test Difference

	Game group	*Control group*
Mean	0.381578947	-1.130434783
Variance	3.773391813	3.550395257
Observations	19	23
Hypothesized Mean Difference	0	
P(T<=t) One-Tail	0.007307054	
P(T<=t) Two-Tail	0.014614109	

difference between the two means for this test. The P values (labeled with P(T<=t)) determine if these results are significant or not. The P value is the chance that the null hypothesis is true. In this case, only about 2% of the range of scores overlap, meaning the other 98% do not overlap. Therefore, these means are significantly different. It is generally understood that if the P value is below .05 (less than a 5% overlap), the two means are significantly different. There is no significant difference in the pre-test scores between the game group and control group students.

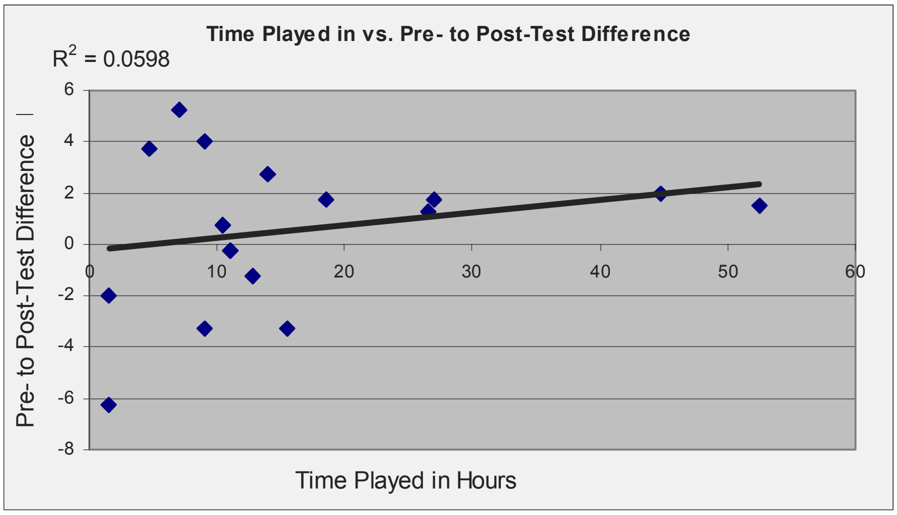
Table 6 shows the statistics for a comparison of the differences between the pre-test and post-test, comparing the game and control groups.

The game group, on average, did 3% better on the post-test than the pre-test. The control group did about 6% worse on the post-test that the pre-test. The drop in scores for the control group is most likely related to taking the post-test right after a nine-day holiday from school. The difference between the two groups is 9%. Since the P value is less than 0.5, the difference is significant between the pre-test to post-test differences of the game group compared to the control group. The game group did 9% better than the control group.

Since this first study completed nearly half-way through the year, only part of the Algebra 1 curriculum topics had been covered in the year. The data from the questions of topics covered so far in the course from the first study completed were pooled together. This subset of the data brought a whole other possible set of tests. The comparison shown in Table 7 proved to be statistically significant.

This t-test in Table 7 compares the average difference from the pre-test to the post-test between the game group and the control group for

Figure 1. Playing time vs. post-test scores



the 10 questions that tested algebra topics already covered in class. The results show the same trend as the fully graded test. The game group rose slightly while the control group fell greatly. The variations are statistically significant.

Although there were no statistically significant results relating the hours of playing the game to any scores, the graph in Figure 1 shows the relationship of game-playing times to pre- and post-test differences. There were no negative effects on scores from playing the game.

Each of the diamonds in the graph represents a single game group student, where the values on the x-axis shows the number of hours that a student played *Math Blaster Algebra* and the y-axis represents the difference from the pre-test to the post-test. This trend line is used to determine if there is a correlation between two values, time spent playing the game and pre to post-test difference. At the upper left of the graph is the R^2 coefficient, which determines whether these two values are correlated or not. Normally it is accepted that if it is above .3 or below -.3, then it is correlated, either positively or negatively. In this case, there is no strong correlation. It may be important to note that there was not a negative correlation with the amount of time spent playing and any grades or scores.

While the positive results of 9% better for the game group were great for such a short period of time, there were no significant conclusions that could be made about the grade averages, or the Texas standardized tests, or the time spent playing the game.

Second Study Data and Results

Since there were such positive results from the first study, a second effectiveness study was organized. The second study was designed to last for most of the second semester. The study procedures were identical to the first study. Ninth grade Algebra 1 students from John Jay Science and Engineering Academy were invited to participate. Each of the students in the new game and control groups took a pre-test and post-test before and after the study period. For those who were in the first study, their post-test in the first study served as their pre-test in the second study, since the second study started within a month of when the first one ended and the students had a holiday in between. The second study lasted over three times as long, a total of

16 weeks, and more school-generated data was available. At the end of the study period, there were 19 students in the game group and 15 in the control group. The average pre-test score was 5.73 with a range of 1.5 to 13.75 for the game group, and 4.75 on average with a range of -0.5 to 14.75 for the control group. The average post-test score was 7.40 with a range of -1.0 to 16.75 for the game group, and 8.86 on average with a range of 3.0 to 20.75 for the control group. Table 8 shows these values for the game group in addition to the play times that ranged from 1.16 to 68.33 hours.

There were some anomalies in the timesheets that students used to record their playing times. For instance, students played regularly for the first six-week grading period, but many did not play the game much after that period. There was also one student who played enough to fill up one timesheet, but just stopped playing even though the instructions on the timesheet say to continue on the back or ask the teacher for another timesheet. What was even more damaging is that there were about six students who were missing some piece of data, such as a post-test since they were not

Table 8. Second study summary data

Second Study Game Group	Pre-Test Score	Post-Test Score	Pre to Post-Test Difference	Time Played in Hours
Average	5.73	7.40	1.67	13.31
Highest	13.75	16.75	3.0	68.33
Lowest	1.5	-1.0	-2.5	1.16

Exhibit 2.

•	Pre-test scores, between groups
•	Post-Test Scores, Between Groups
•	Pre-test to post-test difference, between groups
•	Game group pre-test to post-test
•	Control group pre-test to post-test
•	Average number attempted from pre-test to post-test in game group
•	Average number attempted from pre-test to post-test in control group
•	Game group percent answered correctly from pre-test to post-test
•	Control group percent answered correctly from pre-test to post-test
•	Game group percent answered incorrectly from pre-test to post-test
•	Control group percent answered incorrectly from pre-test to post-test
•	Game group 3rd grading period to 6th grading period
•	Control group 3rd grading period to 6th grading period
•	Game group 3rd grading period to 4th grading period
•	Control group 3rd grading period to 4th grading period
•	Game group 4th grading period to 5th grading period
•	Control group 4th grading period to 5th grading period
•	Difference from 1st-3rd grading period compared to 3rd-6th for game group
•	Difference from 1st-3rd grading period compared to 3rd-6th for control group

available the various times the post-test could be given. These students had to be removed from the study. There were some students who did play the game, but had no timesheet to return. These students were not used in analysis of the time spent playing the game.

More t-tests were performed since there were data over the three-month period. The additional t-tests are shown in Exhibit 2.

No significant results were found with the data from this second study. Also, there were no significant results looking at the pool of students who were in both game groups (compared to students in both control groups). It is interesting to note that there were no negative impacts to scores and grades related to the time spent playing *Math Blaster Algebra.*

The data may have been inconclusive because the students were not playing as much as expected. The students in the longer study played, on average, three hours less than the students involved in the first, even though the second study was over three times as long in duration. The students who participated in the game groups spent 276 hours playing the game in the first study and 213 hours in the second study. The game group students spent over 489 hours more interacting with algebra concepts than they might have without these effectiveness studies.

Future Studies

There studies are intended to be a starting point. There are many additions, corrections, and extensions that can be made to improve other studies. Beyond the significant result of the first study, there was much learned from both of these studies. Some things to consider for future studies are having:

- More students participate
- A longer time period to play
- A controlled and monitored play environment
- A more standardized or normalized testing instrument
- A continual motivation for the students throughout the study (extra credit from teachers, for example)
- Different games
- Different subjects

There is a plan to perform more effectiveness studies on *Math Blaster Algebra* at a couple of high schools in the San Antonio area for future academic years.

FUTURE OF GAME EFFECTIVENESS

Educational computer games are becoming more prevalent as technology becomes more and more available in homes and schools. This segment of the gaming industry is growing each year. Perhaps this growth is due to the amount of anecdotal data that indicates subjectively that students are benefiting from the use of these games. What needs to be done to show scientifically and objectively how effective these games really are or can be?

First of all, more effectiveness studies need to be performed on any educational software including games. Second, more educational computer games should be developed. Third, as educational computer games are developed, more attention can be paid to the method of instruction and practice with lessons from game theory, instructional design, learning theory, and intelligent tutoring systems.

As we show that educational computer games can be effective, we see that they can be used in and out of the classroom as another teaching method. Students could elect to take classes and cover subjects by a game method, for example, in addition to classroom style or group work.

As we see more games with artificial intelligence (AI) and smart agents in them, we could put an AI player into an educational game where the goal of the AI is for the student to learn. The game could be like an intelligent tutoring system in a game setting and can point a student to an efficient and effective path for learning. The goal of an agent could be directed by a smart instructional navigator that selects material to present based on the play so far. When a game is multiplayer, the players could be encouraged to work cooperatively and potentially learn more. The AI could act in a way that directs students toward an equilibrium point.

As advancements in technology make it much more possible to develop realistic graphics and sound, the possibility to truly engage the student into the learning experiences becomes a greater task for the game developer. We now have dual processors; Direct X and Open GL graphics libraries; 3D graphics tools such as Maya, Lightwave, and 3ds Max; and gigabyte and terabyte storage capacities for many computer systems. The ability to create virtual reality systems promotes endless possibilities for learning. Expectations will be high to make educational games both effective for learning as well as engaging and interesting.

With bandwidths being capable of supporting more activities on the Internet, computer usage is being drawn to Web-based services. The gaming industry has taken advantage of this opportunity with games that allow for thousands of users to play a game simultaneously. A good example of this MMORPG (massively multiplayer online role-playing game) is Blizzard's *World of Warcraft,* which had 8.5 million subscribers as of March 2007 (Blizzard Entertainment, 2007). Some online services allow users to create their own online communities and worlds such as in *Second Life.* Some educators have used *Second Life* as a support community for education (Linden Labs, 2007). Perhaps the future will see the gaming industry offer subscriptions to educational environments. These worldwide environments will make learning interactive, educational, fun, and potentially collaborative.

CONCLUSION

Only the future will tell what the demand is for educational computer games. These games will only get the chance to be effective if people make, buy or subscribe, and play them. The games must be attractive and engaging. More educational computer games should be created and developed in ways that are effective in teaching. Developers can use lessons from many disciplines such as intelligent tutoring systems to produce games that engage the player's interest and are effective. Also, higher grade levels and adult education topics could use more computer games that teach.

One effectiveness study on *Math Blaster Algebra* showed the potential for commercially available educational computer games to make a positive impact on student learning and understanding of algebra. If this result can be extrapolated, then other educational computer games should be able to positively impact students' learning and understanding for other subjects. It was shown that although there was not always a positive impact, there was not a negative impact on test scores and grades as a result of the time spent playing an educational computer game.

Studies must be done to determine if these games are effective in teaching and supporting learning of the desired content. More effectiveness studies can be easily performed improving on the procedure given in this chapter.

Maybe the real value of playing educational computer games is to provide a motivation and incentive for students to play around with whatever subject that game may cover, spending more time with the subject matter.

REFERENCES

Blizzard Entertainment. (2007). *World of Warcraft®: The Burning Crusade™ continues record-breaking sales pace.* Retrieved July 8, 2007, from *http://www.blizzard.com/press/070307.shtml*

Burns, H., Parlett, J., & Redfield, C. (1991). *Intelligent tutoring systems: Evolutions in design.* Hillsdale, NJ: Lawrence Erlbaum.

Carnegie Learning. (2007). *Carnegie Learning: The cognitive tutor company.* Retrieved July 12, 2007, from *http://www.carnegielearning.com/approach_research.cfm*

Educational Software Preview Guide Consortium. (2007, June 29). *Educational software preview guide.* Retrieved July 5, 2007, from *http://www-ed.fnal.gov/espg*

Gaither, D., & Redfield, C. (2006). Survey of electronic games that teach. *Proceedings of the 2006 Society of Information Technology and Teacher Education International Conference.* Orlando, FL: Association for the Advancement of Computing in Education.

Gagné, R., Briggs, L., & Wager, W. (1992). *Principles of instructional design* (4th ed.). Orlando, FL: Harcourt Brace Jovanovich.

Gee, J.P. (2003). *What video games have to teach us about learning and literacy.* New York: Palgrave Macmillan.

Hall, D. (1987). *A comparative analysis of guided vs. query-based intelligent tutoring systems (ITS) using a class-entity–relationship-attribute knowledge base.* Denton, TX: University of North Texas (and UMI Proquest).

Knowledge Adventure. (2006). *Math Blaster.* Retrieved January 28, 2007, from *http://www.knowledgeadventure.com*

Knowledge Share. (1998). *SuperKids educational software review.* Retrieved January 28, 2007, from *http://www.superkids.com/aweb/pages/reviews/math/algebra/1/blaster/merge.shtml*

Linden Labs. (2007). *Second Life education.* Retrieved July 8, 2007, from *http://secondlife.com/education*

Luckhardt, C. (1989). *N-person game playing and artificial intelligence.* Ann Arbor, MI: University Microfilms International.

Michael, D., & Chen, S. (2006). *Serious games: Games that educate, train, and inform.* Boston: Thomson Course Technology PTR.

Murray, T., Blessing, S., & Ainsworth, S. (Eds.). (2003). *Authoring tools for advanced technology learning environments: Toward cost-effective adaptive, interactive and intelligent educational software.* Dordrecht, The Netherlands: Springer-Verlag.

Osborne, M., & Rubinstein, A. (1994). *A course in game theory.* Cambridge, MA: MIT Press.

Pensky, M. (2001). *Digital game-based learning.* New York: McGraw-Hill.

Randel, J., Morris, B., Wetzel, C.D., & Whitehill, B. (1992, September). The effectiveness of games for educational purposes: A review of recent research. *Simulation & Gaming*, *23*(3).

Redfield, C.L. (1995). Turning a CBT into an ITS. *Proceedings of the 7th World Conference on Artificial Intelligence in Education,* Washington, DC.

Redfield, C.L. (1999, March). Sky's the Limit Charter School: Offering a tutor-based curriculum. *Proceedings of the 1999 AACE International Conference of the Society for Information Technology and Teacher Education.* San Antonio, TX.

Redfield, C.L. (2000, November). Computer tutors fulfilling curriculum topics. *Proceedings of WebNet 2000,* San Antonio, TX.

Redfield, N., Gaither, D., & Redfield, C. (2007). Educational game effectiveness. *Proceedings of the 2007 AACE Conference of the Society for Information Technology & Teacher Education,* San Antonio, TX.

Steuck, K., & Meyer, T.N. (2003). *The fundamental skills training project.* Technical Report

AFRL-HE-AZ-TR-2003-0041, Human Effectiveness Directorate, Air Force Research Laboratory, USA.

Texas Education Agency. (2007a). *Student assessment division: About the student assessment program*. Retrieved July 11, 2007, from *http://www.tea.state.tx.us/student.assessment/about/overview.html*

Texas Education Agency. (2007b). *Texas Essential Knowledge and Skills (TEKS)*. Retrieved July 11, 2007, from *http://www.tea.state.tx.us/teks/*

Wikipedia. (2007). *Knowledge Adventure*. Retrieved July 6, 2007, from *http://en.wikipedia.org/wiki/Knowledge_Adventure*

KEY TERMS

Artificial Intelligence (AI): A branch of computer science that attempts to have computers and computer programs do things that appear smart or intelligent; knowledge representation and gaming are two areas within AI.

Computer-Based Training (CBT): A process of teaching and learning that is executed with software applications on a computer; the student is, in effect, trained by the computer.

Computer Off-the-Shelf (COTS): Computer products or software that are ready-made and available for sale, lease, or license to the general public.

Equilibrium Point: A set of strategies and payoffs for a multiplayer game that is the best that each player can do, given the other players keep the same strategy; in a two-person game, it is called a saddle point.

Game Tree: A representation of the play of a game where the root or first node is the initial state of a game, the first level or ply is all the possible moves of the first player, and the content of the nodes are the resulting states of the game; the leaf nodes represent when the game is over.

Intelligent Tutoring System (ITS): A computer system that tutors a student on some subject matter by presenting course content based on a model of the student. An ITS typically has four components: interface module, instructional module, expert model, and student model.

Perfect Information Game: A game where each player is aware of all the actions and consequences of moves of all the other players.

Serious Games: Games used for training, advertising, simulation, or education that are designed to run on personal computers or video game consoles. These games are not only entertaining, but have some kind of learning value associated with them.

Strategy: The method of play for a player to play a game; the rules by which a player selects the move to make at any given point in a game.

Student Model: A representation of the current state of what a student knows in relation to material that is being presented in an intelligent tutoring system.