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What is This?
Teaching Algebraic Concepts via Serious Games on a Tablet PC

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Schools and educators continue to explore new technology-based techniques and tools to enhance student education. However, within the subject area of mathematics, and specifically algebra, traditional methods of instruction such as using graphing paper and blackboards are still heavily relied upon. Using new technologies to extend these traditional methods could be used to enhance learning while keeping the format that has proven to work. Tablet-based PCs and serious games are two tools that could be used together to improve learning. This research is based on the serious game prototype developed by Tom Carbone, which utilizes the Tablet PC and an electronic version of graph paper. During the course of the present study, the tool was modified based on the findings from a usability analysis (expert review) and a focus group with educators. The information received from this group of studies began the validation process to show that Tablet-based PC games might be a profitable teaching tool for algebraic education, and future research should be conducted with end-users to gain their approval and insights.

INTRODUCTION

Algebra is the point in math education where many students begin to struggle with understanding and applying mathematical concepts. The potential in both males and females for mathematics may be underdeveloped in school (Lupart & Pyryt, 1996). Therefore it is essential to address both teaching instruction and student motivation. Teaching instruction has changed throughout the years from utilizing blackboards, to overhead projectors, and now computers with PowerPoint and non-interactive media. However, it is important to note that an essential part of the natural and engineering sciences is on interactive learning or “hands-on-training” (Sadker & Sadker, 1994). Therefore, often times a combination of technology and blackboard is used to incorporate interactive learning, making the Tablet PC or graphics tablet a viable option for teaching and learning within an interactive environment. The second issue is on student motivation. Game-based technology is becoming a more highly accepted tool that provides motivation and learning within multiple areas of learning, including mathematics (Randel, Morris, Wetzel, & Whitehill, 1992). Therefore, we propose that Tablet PCs and serious games are two tools that could be used together to improve learning.

Tablet PC

The graphics tablet, also known as the digitizing tablet, graphics pad, or drawing tablet, is an input device that is powered by the computer. The Tablet is built with an ergonomic design that allows one to write or draw with a stylus or puck directly on the screen.

Even though current use for tablet technology is in the niche market, research suggests the Tablet PC to be a viable instructional tool for faculty and students (Willis & Miertschin, 2004; Mock, 2004). Multiple colleges and universities, such as Notre Dame, Virginia Tech, and MIT, are beginning to see the benefit of this new technology ranging from a teaching tool, to distance learning, to a design tool for designing robots (Loch, 2005; Loch & Donovan, 2006; Dahlmann, Jeschke, Pfeiffer, Scheel, & Thomsen, 2006; Tront, 2007). This research suggests that the Tablet PC allows for increased hands-on experimenting, transition from teacher-led to student-centered learning, ability to access modern scientific software at an early stage in order to increase motivation, and an improvement in advanced mathematical comprehension and soft skills.

The Tablet PC can provide an interactive means of teaching and learning new information in the mathematics-based arena. This technology allows students to work with multiple representations, formulate and test hypotheses, visualize difficult math concepts, build knowledge, create and experiment with mathematical models, and develop problem solving abilities while receiving immediate feedback (Kosheleva, Medina-Rusch, & Ioudina, 2007). In the research on usefulness of electronic ink for teaching math, Loch (2005) found positive affect towards using this technology. Out of 65 subjects, 85% preferred writing in the electronic workbooks; 80% preferred the lecturer to write on the computer; 79% of subjects could read the writing; 92% were in favor of amended notes being available on a website. The Tablet PC technology in mathematics education has also led to higher scores, increased speed in covering material, and increased understanding of mathematical content (Loch, 2005; Loch & Donovan, 2006).

Serious Games

A serious game is one developed with a purpose other than entertainment, typically used for education (Lupart & Pyryt, 1996; Johnson, Viljalmsson & Marsella, 2005). The intent in using a serious game is to assist in building a basic understanding
of algebra concepts through repetition in a game environment. A serious game approach was not chosen at random; rather, it was a logical conclusion by the game designer, Tom Carbone, reached by an understanding of the target audience and the benefits of using instructional games.

The audience for serious games is not only a factor in the game design, but a justification that serious games are the right approach to solving the problem. Our audience is from a generation that grew up with video games on PCs and consoles. Authors like Marc Prensky (2001) and Karl Kapp (2007) have made the connection between age groups and their acceptance of technology. The students who we will be targeting are the perfect age group to be reached by serious games. Instructional games like this one may be an improvement over existing methods and tools currently being used in classrooms.

**Current Study**

The current study aims to show that tablet-based educational games are a valid teaching tool for basic algebra concepts, based on feedback from experts on the design of the game and experts in education. This project is an extension of Tom Carbone’s development of a serious game for algebra education. This game is designed to combine traditional teaching methods and game elements in order to improve teaching of algebra concepts, specifically the slope of a line. The math being presented is no different than the exercises students currently use but the presentation of the material is what we aim to improve. Since many parts of algebra lend themselves to a pen-based interface, the tablet PC is the next most natural way to teach and learn algebra.

Our research aims to create a tool that can be used to supplement traditional teaching and apply the algebra concept of slope of a line in a novel way to the students. The game was created to focus on the two most common forms of the linear equation: the standard form \((AX + BY = C)\) and the slope-intercept form \((Y = MX+B)\). There are three approaches to the material, each designed to get the student accustomed to seeing the equations and visualizing them graphed on a coordinate plane. Three levels are available within the material, which change various objectives about the way the game works, from scoring to content to several other factors. The game software on the Tablet PC is not meant to be a replacement for traditional teaching; it is to be used as a student practice tool. Therefore, the primary goal of this technology is to promote complex learning in an environment that will engage and motivate learners to practice the skills learned from teacher-based instruction.

**METHODS**

**Equipment and Materials**

Although the algebra software is developed to run on any PC with a stylus interface, the HP Compaq tc4400 Tablet PC was used as a platform for this study. This model is lightweight and ultra-portable. It provides all the functionality expected in a Tablet PC, along with a powerful enough CPU to minimize any significant delays in input reaction or other display anomalies. This model also allows the user to snap the display into place over the keyboard, providing a very notebook-like writing feel to the overall experience.

The algebra software was written entirely in the C# programming language, using the Microsoft Visual Studio integrated development environment. The Windows Presentation Foundation (WPF) graphical subsystem API and associate tools were also used as part of the development process.

**Program Layout and Design**

The math being presented is no different than the exercises students currently use; however, the presentation of the material is what we aim to improve. The program consists of three games that are based on linear functions in algebra, including recognition of the “slope-intercept form” \((y=mx+b)\), extracting parts of the equation, solving “standard form” equations \((Ax+By=C)\), and graphing linear equations on the coordinate plane. There are three games with increasing difficulty as the game progresses. All games are timed and a score is generated for correct answers.

For Game 1, subjects are provided with an equation in the slope-intercept form or standard form. The goal is to solve the equation to find the slope of the line or the \(y\)-coordinate of the \(y\)-intercept. Subjects write the answers into an answer box.

![Figure 1. Visual of Game 1](image-url)

The program also evaluates the correctness of the line. The average distance from the actual line is compared against a threshold. A minimum area of the strokes was used to determine the length of line needed to be accepted by the tool. After a response, the correct line is displayed for any incorrect answer.

Game 2 focuses on graphing the line. Subjects are given an equation and asked to graph the appropriate line. A custom error algorithm was created to evaluate the correctness of the line. The average distance from the actual line is compared against a threshold. A minimum area of the strokes was used to determine the length of line needed to be accepted by the tool. After a response, the correct line is displayed for any incorrect answer.
The organization of Game 3 is designed around traditional video game structure. The goal of the game is to use the knowledge of solving equations and graphing lines in order to move a battleship around the screen and fire a laser at moving targets. Subjects are to choose a formula from a choice of three, move their ship to a point on the line, and fire the laser to intersect with as many targets as possible. A scoring bonus occurs for multiple hits.

FEASIBILITY TESTING

The project contained three phases: an expert review of the usability of the tool’s layout and design, an external focus group with educators, and implementation of feedback. Data gathered from these phases provide measures that will demonstrate the potential usability and feasibility of this tool. Phase 1 consisted of an expert review by members of the Human Factors Psychology Discipline who have published in usability. The information gathered (over four sessions) is documented and analyzed by the group. Requirements gathered from this phase that could be implemented within the scope of the project were incorporated into the software (see Table 1). For phase 2, educators from the university-level algebra department were chosen as a representative of a target audience of educators who might support the use of the system. The educators provided feedback based on the educational soundness of the tool (see Table 2). Phase 3 discusses implementation of feedback from Phase 1 and Phase 2. From our analyses we hope to demonstrate that the tool is a usable and feasible teaching tool of algebraic concepts.

Phase 1: Expert Review of the Layout and Design

Using Nielsen’s (2005) list of usability heuristics with their corresponding definitions, three researchers evaluated the user interface of the algebra game and evaluated it on its level of user-friendliness. This method is often used to identify major problems in the design and layout of a tool and to assign the identified issues a priority rating (Nielsen, 1994). Each researcher spent, on average, 45 minutes playing the game and working with the interface. During this time, researchers rated the interface on each of the 10 usability heuristics. After each had the opportunity to work with the game, they met and came to a consensus on what the main priorities and recommendations would be for the developer. As a group they rated each area from 1, no change is needed, to 5, critical changes that need to be made. The results of this usability analysis are summarized in Table 1. Changes to the system were made prior to the Phase 2 focus group.

Phase 2: Educator Focus Group

Participants consisted of three faculty members (a lecturer, an instructor, and a graduate teaching assistant) from a university mathematics department. The subjects were chosen based on their teaching abilities and involvement with the College Algebra classes. The focus group members used the tool, filled out a satisfaction survey on a 7-point Likert-type scale (1, would not use / did not like, to 7, would use / liked very much), and provided oral feedback for the tool to determine the educational soundness of the tool.

Currently the teacher focus group uses a blackboard with some use of an overhead projector to teach college algebra. While they were all very likely (M = 6.67) to try something new in the classroom and very likely to use new technology (M = 6.33), there was some dispute to using the Tablet PC (M = 3.00) as a teaching tool. The focus group, however, did feel that the Tablet PC could be beneficial for student use (M = 4.33). While they had some mixed feelings toward the algebra game, they all agreed that the game would not hinder any student, and may be beneficial for student use (M = 6.33). While all members agreed that they would not use the algebra game as a primary means to teach slope of a line (M = 1.0), two members of the focus group said they would definitely (M = 7.0) use the algebra game as a supplementary means to teach slope of a line. Through open-ended questions and oral feedback, the focus group determined that the algebra game provided a “skill and drill” approach that is best used as a practice tool. They felt that it provides a similar structure in the order of concepts (slope, y-intercept, graph, application) and progression of difficulty. They believed that the game’s best target group would be middle school and high school algebra students. In addition, they provided feedback on each game based on their opinions about future student use, as seen in Table 2.

Phase 3: Implementation

The feedback from Phases 1 and 2 of this research varied greatly, with many subtle changes being requested alongside several large-scale modifications to the interface and flow of the experience that was outside the scope of the developer’s
ability to change within the time limits of this project. Some of each type of request were implemented as part of this study, and can be broken up into the following groups.

**Adding directions to game flow.** Although the game was designed as a “pick up and play” type experience, the lack of on-screen directions immediately became an issue. The problem was approached from two directions, since the game had not been designed with these flow elements in mind. Not only did the game software need to be modified to accommodate the additional help screens, but an off-line tool needed to be developed to allow effective creation of the new screens themselves.

The game software was modified to integrate help screen info before each game type. The particulars of what was on the screen, as well as the number of screens, could be easily varied per game type. After initially requiring a tap to proceed, a “Continue” button was added to be sure that screens could not be skipped accidentally. In the final revision, a “Back” button was added as well, to allow more complete user-controlled navigation of these screens.

A help-screen authoring system was also developed, making the creation of the assets a much more efficient, seamless process. The instructor is presented with the actual game interface, and is free to use the main canvas to write the appropriate instructions for the level. Using this system, 20 different custom help screens were created for the game to accommodate the additional help screens, which re

Table 2.

**Teacher feedback on the games and instruction quality**

<table>
<thead>
<tr>
<th>Game 1</th>
<th>Game 2</th>
<th>Game 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Did not know they were supposed to put in slope OR y-coordinate of y-intercept</td>
<td>Game accepted a line that only had 2 points that were close together, but did not accept 2 points on the intercepts. The teachers feel that is more important to have plotted points on the intercepts than random line points.</td>
<td>Instructions confusing</td>
</tr>
<tr>
<td>Make box bigger for input</td>
<td>Teachers got frustrated with error margin on lines. They felt they were “close enough”.</td>
<td>Instructions say “ships” so they did not know to shoot at all objects</td>
</tr>
<tr>
<td>Make text bigger telling if a y-intercept or slope</td>
<td>More for Game 1</td>
<td>They like the “game” aspect of Game 3 but found it too confusing to be useful</td>
</tr>
<tr>
<td>Color coat input box to help differentiation</td>
<td>More time for Game 1</td>
<td>Need erase button on game 3</td>
</tr>
<tr>
<td>More time for Game 1</td>
<td>Teachers did not realize game was over and to go on to the next game</td>
<td>Time did not stop game at 0 and went into negative time</td>
</tr>
<tr>
<td>Teachers did not realize game was over and to go on to the next game</td>
<td>Teachers did not realize game was over and to go on to the next game</td>
<td>Delete picture of the flag (was offensive to shoot a flag)</td>
</tr>
<tr>
<td>Game 3</td>
<td>BattleShip picture confusing</td>
<td>Difficulty to use the movement keys to move the battleship</td>
</tr>
<tr>
<td></td>
<td>Think about ways to remove moving the battleship</td>
<td>Battleship picture confusing</td>
</tr>
</tbody>
</table>

A help-screen authoring system was also developed, making the creation of the assets a much more efficient, seamless process. The instructor is presented with the actual game interface, and is free to use the main canvas to write the appropriate instructions for the level. Using this system, 20 different custom help screens were created for the game to guide the user through the experience.

**Layout of user interface.** Initially, the layout of the user interface had all information for the user on the right-hand side of the screen. User feedback drove a major change in the look of the interface, which resulted in all the information being placed in the upper portion of the screen, with the entire canvas stretching right to left. This new layout allows right-handed users to experience the game without covering up game data with their hand as they write their answers.

Since WPF was used in the development of the game, the new layout was accomplished by modifying the appropriate
.XAML file, which contains size, position and other layout information for the various pieces in the interface. However, once the main ink canvas changed dimensions, several other updates were required to the code. Primarily, these changes revolved around the fact that lines looked different now, so any code that involved rendering or recognizing lines in the main ink canvas needed to be updated.

Game user feedback. Game 1 calls for students to analyze a linear equation, and extract out the slope and y-intercept information. Users are asked to write their answers as numbers in a small ink canvas, and press the submit button to register their answer to the computer. Early on, users noted problems when answering questions incorrectly, and questioned the validity of the testing. Changes were made to provide the users feedback, based on the three possible reasons for getting the problem wrong. First, if the user’s input was not recognized as a number, a message “I don’t understand” was printed. In this case, the user was not penalized, and the same question remained to be answered. Another possibility was that the user entered the correct answer, but was recognized as a different number. Alternately, the user may have simply entered the wrong answer. For example, a message like “Answer is -2, not 2” tells the user that the computer recognized their input as 2, and that the correct answer was -2.

Small user interface changes. In addition to the large scale changes mentioned above, many small usability tweaks were made after both surveys. Initially, the system depended on the user tapping in several places to “enter” their answer. This tap was problematic, and often times resulted in inadvertent entries being examined by the computer. When these taps were replaced with requiring the user to touch the “Submit” button, the interface became much more dependable.

Additionally, an eraser tool for the main ink canvas on Game 2 was added, as well as a red dot on the laser cannon in Game 3, and changing the color of the error line in Game 2 to red. While each of these changes did not amount to much in terms of improvement, the cumulative effect of them made for a noticeable improvement in the overall polish and usability of the interface.

CONCLUSION

New technologies are rarely accepted into any institution immediately. They must first withstand inquiries into their validity and undergo an iterative process to improve effectiveness. This is especially true in an academic setting where methods are tested and proven over time. The mathematics taught in an algebra class is not going to change. To improve the education our students receive we need to look into the methodology being employed and develop it with new ideas and technology. Our research shows that teachers are willing to adopt new technologies if it can be proven effective.

Demonstrating that the tablet-based games are effective will take much more research but acceptance of the technology by students and teachers are important first steps. The improvements to the educational software installed on our tablets are numerous and significant. After only a few rounds of feedback analysis and implementation, the software has improved greatly. This speaks to the adaptability of the system and illustrates another important step in confirming the viability of the Tablet PC as an instructional tool. As the system and technology improve, serious games could be as prevalent in an algebra classroom as graphing paper and a blackboard are today.

Future research should be conducted testing this game and the idea of practicing math skills via a serious game should be brought before the end-users: students.

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