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Blending instructional design principles with computer game design: The development of Descartes' Cove

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This paper describes a research and development project called Descartes' Cove, which blends instructional design principles with the compelling elements of computer-based role-playing games to create mathematics adventures for middle school and early high school students. The development methodology drew on research in math education, psychology, human-computer interface design, and game design, and relied heavily on prototype evaluations by students and teachers. The six CD-ROMs, released in spring, 2005, emphasize investigation and exploration. Each contains a different role-playing adventure with vivid graphics, animations, music, and increasingly more advanced math challenges based on specific standards areas established by the National Council of Teachers of Mathematics (NCTM).

Introduction

Growing access to computers both at home and at school has fueled an enormous amount of educational software development. Yet despite the widespread availability of computers and the growing number of software programs, educators find many obstacles to their use and provide mixed evaluations of their effectiveness (van Dam, Becker, & Simpson, 2005). For example, Williams, Boone, and Kingsley (2004) found that teachers reached general agreement about the need for significant improvements in educational software. The most commonly mentioned criticisms concerned shortcomings in the instructional design of most products, as well as in their educational content. The teachers recommended that the software should emphasize more higher-order thinking skills rather than just drill and practice, and should take better advantage of inquiry methods. Teachers also faulted educational software developers for their failure to systematically incorporate input from teachers, and also for the software's inconsistent alignment with the curriculum.

A parallel upsurge in software development has occurred in the world of video games and recreational computer-based games, which have captured the imaginations of youth around the world. Many of these games, such as the role-playing adventures, contain compelling features that maintain response and involvement at extremely high levels, sometimes lasting many months or even years. The psychological environments of computer games with their intermittent schedules of reinforcement have been refined considerably, drawing on findings from decades of research in the social sciences on motivation and persistent behavior (Wallace, 1999; 2004).

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The motivational aspects of computer games have attracted the attention of educational software developers interested in creating more engaging programs for students, and the product category called "edutainment" was the outcome (Maushak, Chen, and Lai, 2001; Quinn, 1994). Research on the effectiveness of the many varieties of this kind of software, however, has been limited, and little is known about issues such as design strategies, interfaces, curriculum integration, teacher training, classroom use, or student performance. This paper describes the Descartes' Cove Project**,** which involves research and development of edutainment software designed to engage students in middle school and early high school in challenging and advanced mathematics.

The Descartes' Cove Project

The Descartes' Cove Project was launched by the Johns Hopkins University Center for Talented Youth (CTY) in 1999. The mission of CTY is to conduct research on high academic ability, and provide academic programs, guidance, and counseling to highly able students around the world in grades K through 12. The Cove project leverages the motivational power of role-playing games for math learning, and capitalizes on advances in cognitive psychology, human-computer interface design, instructional design, and math education. Funded by the AT&T Foundation and the Toyota USA Foundation, the research and development project involved the combined expertise of students, educators, psychologists, parents, software developers, graphic designers, animators, and musicians.

The goals of the project were to:

- research and apply strategies to effectively combine elements of computer games with research-based instructional design principles;
- involve students, parents, and teachers as key stakeholders, beta testers, and evaluators;
- cover six of the standards areas for math, established by the National Council of Teachers of Mathematics (NCTM);
- create engaging software that can be used flexibly by teachers and students, that demands higher order thinking skills, and that challenges even very bright math students.

Development methodology

The development methodology for the project emphasized the combined use of instructional design principles and elements of computer games known to engage students and maintain response levels. Prototypes were developed and evaluated extensively by students and math teachers, to refine the elements that would be incorporated in the design. Initially, the gaming environment involved a series of interactive puzzles, but evaluation of early prototypes demonstrated that a more focused, first person role-playing game with clear goals and a solid storyline was preferred by the students. As a result, the gaming environment was changed to a series of six role-playing adventures that occur on a deserted island, once inhabited by René Descartes. In a leaky lifeboat, students survive an ocean storm and become marooned on the Cove's beach. Once they gather their gear, they can begin one of the six adventures through the island's underground rivers, castle, jungle, mining caves, and volcano paths. They collect coins and inventory items as they solve math problems, explore new areas, and eventually reach Hypatia's Inlet where the problems are most difficult. Successful students can attempt the Final Quest (final exam), and enjoy a breathtaking escape.

The main features of the Cove, described in the following sections, show how the project draws on instructional design principles and blends certain key elements of role-playing games to create the software. Evaluations from the key stakeholders were also critical to the development decisions.

General concepts and interface issues

Research has clearly demonstrated that previous experiences, such as those acquired while learning to use various software products, establish schemas that facilitate performance in similar situations, such as recognizing significant objects on a computer screen (Pillay, 2003; Kaufman, Patel, & Magder, 1996). For example, people who are familiar with Microsoft Word or Excel adapt easily to other software products in the same family since they share many characteristics. Mouse and keyboard actions become more predictable, reducing the learning curve. For the Cove, this research was particularly salient, but choices about suitable elements were more difficult because game interfaces are more variable compared to office productivity software. Also, experiences with the different games varied, especially between students and teachers. Most students had experience with some computer games, while most adult teachers had not. Despite the variation, however, the students had developed some common schemas about how objects can be manipulated, explored, and moved in a game environment. Examples include glowing hot spots on rollover, drag and drop motions, clickable maps, and a navigation bar with backpack to hold inventory items.

Focus on exploration and investigation

Early evaluations indicated that students preferred an exploration approach with minimal scaffolding and instruction. Teachers, especially those with little game experience who did not share the same schemas about a software environment, often did not agree with the students about this design element. Instead, they were more likely to report being "stuck", look for instructions, or assume the software was frozen.

For navigation, and for accomplishing the tasks of the adventure, the Cove relies heavily on investigation and exploration. The same approach was applied to the mathematics content, partly to demand that students apply reasoning skills and higher order thinking. Math problems are hidden behind rocks, butterflies, secret doors, or other features embedded in the Cove's environment. Students attempt the problem first, buy a hint if needed, but the explanation of the concept itself is embedded in the back of Descartes' Notebook, within the Secret File Solution. This detailed explanation of the problem is only accessible after the student has made an effort to solve it.

Scaffolding in the form of audio instructions, was removed after evaluations were conducted of the prototype. Students found the audio instructions for each problem distracting and overlong, and preferred to investigate on their own. All spoken voices were removed from the program, and music and sound effects were added.

Opening sequence: Setting the stage and equipping the explorer

In role-playing games, the opening sequence is often very cleverly designed to introduce the setting, acquaint the player with the game's navigation, goal, and toolsets, and develop the motivational theme. In Riven, for example, the player learns of the predicament of the main characters and how badly help is needed. Instructions are minimal, and any that appear are typically embedded in the theme rather than introduced in the form of a manual. The Cove follows this principle in the opening sequence. Once students are marooned on the beach, they must explore to find out where they are and what to do next. The opening sequence also provides the equipment needed for the journey.

Starting the journey: Passing the test at the adventure gateway

Each of the six math adventures deals with different standards areas of math, at different levels, and is closely tied to the NCTM curriculum. The order of difficulty of the modules is shown below, from least difficult to most difficult:

Measurement: The Rafting Journey

Number and Operations: The Sailing Ship

Data Analysis and Probability: The Mining Cave Expedition

Algebra: The Underground River Adventure

Geometry: The Secret Castle

Reasoning and Proof: The Volcano Adventure

Before starting each journey, the student must correctly answer the diagnostic problem at the gateway to the adventure. The correct answer might unlock a locked door, start an engine, or unfasten a rope holding the raft to the shore. If the problem is not easily solved, the math content may be too advanced for the student.

Balancing freedom of action and structured learning sequence

Most role-playing games allow considerable freedom of action within segments of the program, but deny entrance to new levels until certain tasks are successfully completed. Instructional design principles place more emphasis on continuous structured sequences, so that the concepts are presented in order, building upon one another. The Cove blends these two approaches. Students may navigate around the different quadrants of the island, solving problems in several different rooms and leaving some for another time. However, toward the end of each adventure when Hypatia's Inlet is reached, the student must solve very challenging, integrated problems in order. To tackle the Final Quest (final exam), the student must have successfully completed certain problems in each quadrant, as well as the ten integrated problems.

Motivation and rewards: Coins, keys, and collections

The Cove includes several internal reward systems that blend elements of role-playing games with best practices in instructional design. Throughout the adventure, students earn gold coins for correctly answering questions, and they earn more if they can solve the problem on the first try, without a hint. Also, like role-playing games, the Cove rewards students by allowing entrance to new areas on the island after the student solves a problem. Correct answers unlock doors, launch rafts, start cable cars, or open other areas. Answering certain problems scattered throughout the adventure allows the student to pick up inventory items that will be needed to build the means of escape from the island. The student can look at the inventory inside the backpack at any time, and can not complete the adventure without collecting all the items.

Academic progress and reporting

Students, parents, and teachers agreed on the need for extensive reporting and tracking of progress. In role-playing games, such reports might simply list the character's total points in several areas, such as magic skills, health, and fighting ability. Instructional design principles for educational software, however, call for far more extensive tracking and reporting tools. These enhance motivation for students, and they can be used for diagnosis and evaluation by teachers. Each adventure in the Cove maintains a file for each student (by student name) that tracks all progress, and displays it in a Journey Report that shows the activity on every problem, including use of hints and Secret File Solution. The student's performance is summarized both by difficulty level and concept area.

Higher-order thinking skills and protocol analysis: The Student's Journal

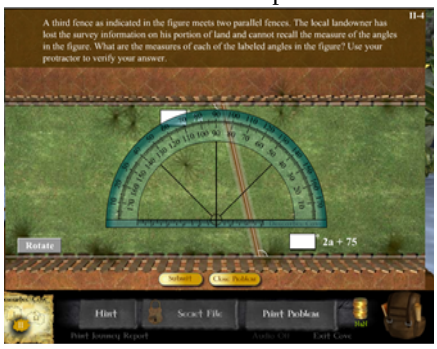
The student's backpack contains a journal in which students can write their own comments about any of the math problems or the adventure in general. The journal is an important element for protocol analysis if teachers or parents encourage its use, one that promotes higher-order thinking and reflection on challenging problems. Students can explain how they attempted to solve particularly difficult problems, print out the document, and then discuss it later.

Final goal: Hypatia's Inlet and the Final Quest

A key feature of role-playing games is a final, very difficult challenge and dramatic ending. Often this is a final battle against a monstrous foe. Though a violent ending is inappropriate for an educational game, the principle of incorporating a climactic ending is another element from role-playing games that can be fruitfully adapted to the educational software environment. For the Cove, with its six different adventures through different areas of the island, the ending sequence involves the construction of a means of transportation to escape from the island. Once the student has collected all the inventory items and mastered the challenges in Hypatia's Inlet, the Final Quest begins. With each problem, a piece of the vehicle is removed from the backpack and added to the construction site. During the Final Quest, the submarine, biplane, hot air balloon, sailboat, or other means of escape is constructed. After the final exam is completed, the student is prompted to print out the Journal, the Journey Report, and the Student Certificate. The student may then choose to exit the island, which will trigger a dramatic 3-D animation over, on, or beneath the ocean, depending on the vehicle.

Math problems and curricular content

The several hundred word problems contained on the six CDs, developed by a creative team of math subject matter specialists, emphasize higher-order thinking skills rather than drill and practice or exercises. Most involve the context of the Cove's habitat, with problems featuring sailing distances, hidden treasure chests, mosquito populations, gold weights, and similar elements. In Algebra: The Underground River Adventure, for example, the first problem asks students to map the stones in the hot springs pool on a Cartesian coordinate plane. Each room or quadrant in the adventure emphasizes one of the goals established for that standards area. For example, the second area for Measurement: The Rafting Journey is on a raft under a rock bridge, and the associated NCTM learning goal is stated as follows: "Apply appropriate techniques, tools, and formulas to determine measurements". Problems in this area include the use of an interactive, movable ruler and protractor to perform actions in the program and solve each problem. The selection of problems fully covers each of the learning goals in the six math standards.



Flexible teaching and learning strategies

Feedback from teachers who participated in the Cove's development, and the comments found in the study by Williams, Boone, and Kingsley (2004), reinforce the need to design educational software so that it can be used in flexible ways. This consideration was taken into account during the design of the Cove. At home, for example, students can use the Cove to enrich their current math course and solidify their understanding of NCTM standards areas. Teachers can use the Cove for whole group instruction with a laptop and projector, encouraging groups of students to compete on different problems, and using the Secret File Solution as an explanatory device. The Cove can also be used as a reward and as a differentiation strategy in the classroom. Cove adventures provide expanded challenges to highly motivated and able students who have completed the regular assignments and need additional stimulation.

The Center for Talented Youth will use the Cove in the context of distance education for academically highly able students. CTY's technology-based distance education program incorporates a wide variety of

software, and enables students to pursue more advanced and challenging coursework within their schools or during the summer (Wallace, 2005).

Conclusions and Next Steps

Descartes' Cove is a continuing project that combines research on educational software design and mathematics learning, with continued involvement of key stakeholders. Version 1.1 was released in the spring of 2005. As more research is conducted and more feedback obtained from wider use of the Cove software in different settings, additional improvements will be made. Teachers stress that a key reason educational software continues to fall short is inadequate investment in research and development in this area, and more research is needed (van Dam, Becker, & Simpson, 2005). Even basic reviews of software for educational content and effectiveness by and for teachers have decreased in number in recent years (Buckleitner, 1999).

Further evaluation of the software and research on its use in educational settings, both at home and at school, will guide future enhancements to Descartes' Cove. Some possible improvements include a Spanish language version, an instructor's edition and manual, and additional instructional aids to help teachers use the Cove effectively within the context of differentiated instructional approaches. The Cove is a work in progress, and as more is learned about how to create effective virtual learning environments, the software will continue to evolve.

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