2006-2590: THE DESIGN PROCESS OF A CHEMISTRY VIDEO GAME

Naveen Nattam, Purdue University

Kermin Martinez-Hernandez, Purdue University

Doug Danforth, Purdue University

Steve Emberton, Purdue University

Ryan Pedela, Purdue University

Eugene Elkin, Purdue University

Kellen Maicher, Purdue University

Carlos Morales, Purdue University

Gabriela Weaver, Purdue University

The Design Process of a Chemistry Video Game

Doug Danforth, Eugene Elkin, Steve Emberton, Kermin Martinez-Hernandez, Naveen Nattam, Ryan Pedela, Kellen Maicher, Carlos R. Morales, Gabriela Weaver

Abstract

This paper details the process used by a research team at Purdue University to map out and design an educational chemistry video game sponsored by the National Science Foundation. The design process developed by the team is significant because it integrates the design process used by traditional video game developers and the process used by instructional designers.

In the past, traditional video games have presented a level of immersiveness and game play that instructional video games cannot match. Instructional multimedia on the other hand has been able to deliver targeted and progressive instruction that commercial video games cannot deliver. In short, there has not been a video game that delivers the immersive and game play qualities of entertainment games coupled with the educational value of instructional media.

The goal of our NSF project is to create a set of research-validated recommendations for the development of science-centric video games. Research in instructional design and cognition have helped guide the types and amounts of educational activities that are included in the game. As a result of the development of a 3D immersive video game that includes chemistry-based challenges, we created a process that allows artists and instructional personnel to create the necessary design documents to make an immersive educational video game. This process was developed over 8 months by an interdisciplinary team of chemistry, computer graphics technology, and computer science students and faculty.

Introduction

The focus of our research is the identification of the motivational elements in video game design and the use of these elements in conjunction with pedagogical techniques to inform the creation of educational video games that are truly engaging to players. In the course of conducting that research, our team elected to create a game to teach chemistry concepts. The game was created using a production process in which game designers, artists, programmers, and subject matter experts colloboratively build the game. This paper focuses on the pre-production work of this team. In other words, the conceptual design of the chemistry and non-chemistry challenges, as well as the design of the game concepts. Figure 1 illustrates the process and composition of the team.

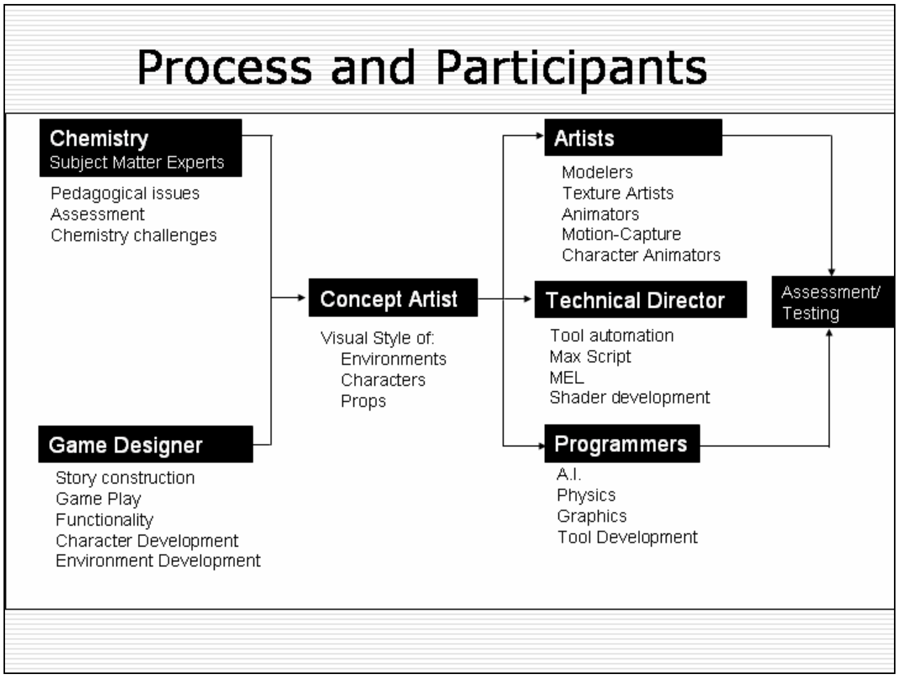

Figure 1. Team Composition and Process

At a high level, the team is organized into 6 distinct areas. The Chemistry subject matter experts (SME) and game designers primarily focus on the creation of educational and non-educational conceptual content. The work from those two teams is fed to a concept artist who is responsible for creating a visual represntation of all of the necessary media assets needed to implement the game. The visualizations from the concept artist are then used by the art team, technical director, and programers to actually create the art assets and code the game.

A playable version of individual challenges of the game ("game segments") are tested by volunteers from our targe audience of high school and college students. Game testing takes on two main forms. First, each game segment is tested for playability and debugging. After revisions based on this round of testing, the game segments are tested for instructional impact. This round of testing involves interviews, "think aloud" strategies, and pre/post surveys to test content knowledge.

Motivation for the Project

The use of digital games has grown exponentially since the early 1980's, when personal computers first appeared. Pong, the first commercial video game, became available in 1974. The oldest of today's traditional college students wasn't born until 1981, a full 7 years later, the year that the IBM PC was introduced (Prensky, 2001). The now ubiquitous nature of computers and computing-capable devices has resulted in making digital environments easily accessible, whether it be at home, school, work or places in between. As a result, there is a generation of people who have grown up not knowing a world without computers, and who have been shaped, possibly in fundamental ways, by access to the tools provided by this digital environment.

Prensky (2001) argues that the current generation of students has a degree of experience with computer games that makes them different as learners than prior generations of students, including their teachers. Research in neuroplasticity (Shaw and McEachern, 2001; Sterr, et al., 2002; Merzenich, et al., 2002; Celnik and Cohen, 2003) supported by studies in brain imaging (Rapoport, 1999) would indicate that it is highly likely that the regular and frequent use of video games and digital multimedia environments by today's students could result in brain organization that is different from that of older, non-game players.

A number of studies have suggested cognitive effects from computer game playing. A recent paper by Green and Bavelier (2003) shows that video-game players outperform non-video-game players on tasks of visual attention capacity, enumeration, and attentional "blink" time. Furthermore, non-video-game players who then trained with videogames for as little as 10 hours were able to demonstrate significant improvements on these performance measures. It has been suggested that the average teenager in America today plays video games for 90 minutes per day (Prensky, 2001). It seems plausible, then, that students in today's classrooms would be capable of processing information presented to them very differently than in the verbal, conceptually linear approach that is still a dominant mode of pedagogy. Today's students may even learn more effectively if material were presented in a manner that takes advantage of their facility with digital environments and, in particular, with digital game environments.

Hitendra Pillay (2003) reported that playing recreational computer games had a positive effect on subsequent performance on computer-based instructional tasks. Furthermore, the type of computer game played by the students influenced the choice of cognitive strategies they used for the instructional tasks. This type of skill transfer would be a strength for students if instructional material shared some of the characteristics of the games these students are accustomed to playing. This supports the notion that the video game format could be effectively adapted to include educationally-oriented challenges.

The use of computer games appears to result in enhanced thinking abilities such as inductive reasoning (Camaioni, et al., 1990), creativity (Doolittle 1995), anticipatory thinking, means-end analysis and parallel processing of information (Pillay, 2003), all of which are desirable cognitive skills for problem-solving in general, and particularly in science. Structural information is the formatting, layout and design of a digital environment and is independent of content but provides the basis for dealing with the content (Mayer and Sims, 1994). Similarities in structural information between games and instructional materials would assist in the skills transfer that would then help students perform better on instructional tasks (Pillay 2003, Spiro and Jehng, 1990).

Instructional Design Process Adaptation

While much work has been published on the adaptation of instructional design models to multimedia development, many of the existing recommendations did not directly map to video game creation. In particular, these models do not address the integration of an instructional activity into an immersive game environment. One drawback is that these model do not consider methods for in-game assessment in a continous real-time environment. The Dick & Carey model provides an excellent model for indentifying instructional objectives, then creating assessment items to measure the mastery of those objectives, and finally the creation of the media assets that will be used to present the material necessary for the mastery of the objectives. However, the model treats each of these components as discreet activities. The model works best for scenarios where the learner will engage in the assessment activities in terms of post-instruction items or even embedded items; it assumes an environment in which the instructional world exists separately from the assessment.

This approach is not applicable to our project design. Within our game, the learner would be immersed in a 3D environment in which there are no explicit instructional or assessment items. The learner never encounters an embedded question or a post-instruction assessment. Instead, we extrapolate the learner's understanding of the instructional material based on their actions inside of the game world. The instructional phase and assessment phase co-exist within the game.

We chose to maintain some elements of published models for instructional multimedia development, but modified the assessment component to allow us to operate in a real-time immersive environment with no explicit instructional presentation. Specifically, we still went through the audience analysis phase, identified objectives, and developed metrics for those objects. However, we elected to map our assessment items to conditions triggered within the game by the learner. Essentially, the action path and success of the player in the game are markers for the learning that is taking place. For example, in one of the game segments the player encouters a chemistry-based challenge in which they must create ammonia using a reactor. In order to assess whether the student has mastered a specific set of instructional objective, we examine how the player has manipulated the game world to complete the task and base our assessment on that information.

Subject Selection for Game Testing and Educational Assessment

The chemistry challenges for the first phase of the project were designed to relate to the environment associated with typical utilities operations associated with a self-contained living environment. One challenge deals with the concept of chemical equilibrium. This chemical concept has a practical application in the need to produce ammonia within the facility for use as a fertilizer for growing crops that are used for nutrition and for revitalization the facility's breathing air. Adhering to chemical principles such as stoichiometry and LeChatelier's principle allows the player to progress by solving the challenge. The chemistry-based challenges are difficult to solve by trial and error, and even this approach will lead to some connection of chemistry concepts. The instructional goal is to make the players more comfortable with their ability to solve chemical problems even when they are not already familiar with them. Having and applying some chemistry knowledge will help the player solve the challenges more quickly.

The challenges are designed to have a natural fit with the storyline of the game and the environment in which the game is taking place. For example, the chemistry challenges leverage various chemicals that would normally be present and available for utilities applications within the facility. One of these challenges is an acid-base related challenge involving the use of sulfuric acid, which is available in our facility for pH adjustment of the water treatment facilities. A different challenge deals with chemically changing the density of a large body of water in order to float a key piece of equipment off of the bottom. It involves the use of rock salt that is present in the facility for the regeneration of the water softeners. We have designed the challenges so that they evolve naturally out of the game's storyline and are embedded in the normal activities of the game, with the goal that the challenges do not slow down or otherwise constrain the game action.

The learning objectives of the challenges are not intended to teach these chemical concepts to the same depth that would occur in a regular chemistry course. Our objective is to involve players in a practical application of chemistry concepts learned in a class. This is expected to result in lowering of student anxiety about chemistry and increase their depth of understanding of concepts that may seem very abstract in the context of a course.

After the chemistry team has a solid idea of the learning requirements for the project, they interface with the game design team to integrate those activities into the narrative of the game.

Chemistry & Design Team Interface

While the chemistry team concentrates on the pedagogical issues of the game, the design team focuses on the creation of the narrative elements and game-play elements necessary for the implementation of the game. An important aspect of positioning the team to work effectively together involved characterizing the types of information that each functional member of the overall project needed in terms of information, and then designing standard templates for various documents used to capture and communicate that information for each challenge.

Another functional area that required attention involved identifying and agreeing on a flow chart that could be used to guide the development of each successive game segment. The flow chart addressed the specific work pieces that need to be developed, and an overall process flow with milestones identified – such as key artifacts, reviews cycles, and approvals. Developing standard informational documents to use as templates and an accepted process flow chart resulted in a congruence of effort that truly accelerated the team's progress.

Creating the Game Design

The game was aimed to be played in a FPS (first-person shooter) style. This was chosen due to its incredible popularity in the gaming market and its easy ability to immerse the player. This brought some initial restrictions to our game. With experience with game mechanics of common FPS games, we knew that our players would need a consistent control set. Essentially this meant that we could not clutter our game with "mini-games" that took the player out of the normal game environment and made them play a smaller game with a different set of controls. This was something we needed to keep in mind considering it would be very tempting to create a different kind of game for each education-based puzzle we created. Analysis of FPS games showed that minute control of objects (example being hundreds of tiny flip switches) would be a poor design implementation. Thus we kept physical representation of puzzles abstract and easy for the player to manipulate. With these concepts in mind, we set about translating our educational ideas into game-play.

When initially creating the design for the game, the chemistry team came up with a list of common misconceptions that freshman level chemistry students have. We took this list and started looking at how these were being taught in class. After analyzing these methods, we took what students were doing there and tried to find a way to fit those activities into a consistent game design. For example, when teaching stoichometry, many teachers use a "nuts & bolts" game where students must balance equations using different kinds of items. We created a rough idea for a puzzle where players would need to pick up and mix different kind of items. After looking at our initial story, we would find a suitable place for this puzzle and some motivation for why the player would need to solve it. In this example, our players reached and elevator that was out of power but could be restored by loading two different types of batteries into a power box. The right combination would create so much output. The players need to solve the equation of balance and activate the machine to move forward in the game. The in-game mechanics were fairly simple. The players would pick up the batteries and drop them into a machine where a screen would show them the results. This keeps the player out of a "mini-game" and in the normal game environment.

This is a typical example of taking a concept straight from a classroom and doing some rough translation. Some examples are a bit harder to translate in that they do not have a direct physical activity we can base our design on. In another puzzle, the players have to create the right equation to produce ammonia. Normally this is an all math problem that students can solve with a piece of paper. In our game, the piece of paper was actually a series of slots that held tanks. There were three types of tanks which represented the three different components in the equation. Players placed the right number of tanks into each slot and activated the reactor to see if the reaction was carried out correctly. They could remove tanks and rearrange them to try to find the right answer. The bottom line with any of our designs was to make sure that the answer the player came up with for the problem in the real world could be easily entered into our game world. This allowed for us to keep the chemistry concepts in but create a gamer-oriented environment for players to try their answers.

Concept Design and Preproduction

In the initial phases of the chemistry game, it was identified that an intermediate step was needed in the development process to provide a buffer between the design and production teams. Initially, the original production pipeline called for all materials to travel straight from the design team to the production team, which mainly consisted of 3D artists and programmers. Originally, it was intended that the designers would be capable of supplying all necessary materials for the game to be produced. Although the design team's materials were fairly comprehensive and detailed, problems arose when the production team began development.

These difficulties were primarily due to the fact that the game design materials were heavily text-oriented and lacked a certain degree of visual sophistication. While the design team provided supplementary floor layouts, charts, and diagrams to describe the 3D environment and game-play, these preproduction materials ultimately proved insufficient to be used effectively by the development team.

These deficiencies became readily apparent when revisions and adjustments to the game were needed. As with any large multimedia project, a number of revisions were needed to account for design problems that were not identified in the initial game design. Unfortunately, many of these problems were not identified until production had already begun; with additional issues arising during usability and performance testing. Some of these problems included:

- Missing visual elements needed to solve the chemistry puzzle
- Control elements such as screens, buttons, and switches that were not readily intuitive to the player.
- Fundamental game-play issues that either made the action too boring or confusing
- Aspects of the chemistry component of the game that were not realistic enough to depict actual chemical processes and equipment

At the time all revisions had to be made directly to the 3D elements, basic game changes proved to be a very difficult and time-consuming process that drastically hampered the flow of production. Since multiple revisions were immediately recognized as frequent and inevitable occurrences of game development, the original production pipeline was abandoned in favor of the current process.

To correct for these inherent problems with the existing production pipeline, it was determined that detailed 2D renderings and simple 3D mockups would be created before primary 3D development and game programming would take place. These visuals, being easier and less time-consuming to create, would allow for the numerous revisions that would ultimately accompany development. 2D renderings primarily consisted of digital sketches in Adobe Photoshop CS2. While traditional renderings were considered, digital images were easier to manipulate and reproduce. These renderings consisted of environments, characters, weapons, and equipment and props.

2D images were primarily used to provide a sense of overall look and style to the 3D artists and programmers of the production team. While they were useful in describing the general look and feel of the game, problems developed when complex objects of specific detail needed to be created in three dimensions. While the 2D depictions provided large quantities of visual information, 3D artists worked more effectively with views of objects at several angles in the modeling process. This was initially addressed by providing 2D orthographic views of objects at various vantage points, but the sheer number and complexity of objects that were required to be rendered made this an inefficient method.

A better alternative was to provide simple 3D mockups using Last Software's Sketchup and Alias Wavefront's Maya 7.0. Sketchup, a simple yet powerful application that allows for quick development of basic 3D models, allowed concept artists to explore a variety of designs in a short period of time. When the final designs of particular elements were decided upon, the concept designers supplied 3D views that the modelers could use to create detailed wireframes.

When more detail was necessary in the concept design, Alias Wavefront's Maya was used to generate geometry for larger, more complex objects and environments. The modeling capabilities of Maya in concert with it's animation, lighting, and shading functions allowed concept designers to explore complex mock-ups that could still be easily revised in a relatively short timeframe.

Game-play Testing

As part of the design process, the team found it necessary to implement a testing procedure that would allow them to make iterative changes to the design of the game. It is worth noting that this testing phase was not meant to validate the educational properties of the game. That type of testing is to be performed after the design of the game has been finalized and is currently being conducted. Results from this phase will be available at the conference. This game-play testing phase is used to improve the playability of the game.

In our tests, we found that constant feedback is needed to assure the player of their actions and that any kind of feedback is good (positive or negative) as long as it is clear for the player to understand. The testing demo we created consisted of one whole puzzle and no action. The basic game mechanics were in the puzzle and the goal of the testing was to see if your puzzle could be understood and solved as well as observe players tendencies during game-play.

When interacting with the world in the game, we found that it was crucial that the player has some form of feedback for their actions. For example, in our puzzle, the player had to place chemical tanks into tank holders. When the player put the wrong type of tank into a particular holder, a form of feedback was needed to tell the player that even though they were wrong, they did do something. In this case, a message stating that the tank type was incorrect appears. As we observed our testers, we found they became confused when there was little to no feedback (especially if the feedback was very vague). This led to them thinking that they were not doing the right thing or just simply not understanding. It was crucial for our game that all interactive aspects of the game are met with some form of feedback. Essentially if the player performs an action in the world, they need the world's recognition to that action and this makes the rate of feedback driven by the player rather then the game.

When players were attempting to solve the puzzle, we found that feedback was good regardless of whether it was positive or negative, however it should be associated with the player's actions. If they did something incorrectly, the players were prompted of the problem. Negative feedback is used to help the player learn and solve the task while positive feedback keeps the player satisfied. Figure 2 illustrates a scene from one of game-play tests in the ammonia reaction puzzle.

Figure 2. Game screen shot

Conclusion

Developing a solid educational game that is sound pedagogically and entertaining requires a design process that integrates educational issues with the traditional game design process. Not only must there be a solid pedagogical foundation in the subject matter and the instructional design, but attention must also be given to the immersive game-play issues. This is not difficult, but it does require a very unique team that tackles these issues during the design phase of the game. The actually programming of the game and the creation of the art assets is labor intensive, but ultimately it is easy. The design and conceptualization of the activities is the most challenging part of an endeavor such as this one. It is during this phase that a very distinct set of interdisciplinary individuals must come together to conceptualize a shared vision for effectively entertaining, instructing, and assessing the learners. In bringing these groups together, it is necessary to keep in mind the different “languages” that they speak and to find effective and efficient means for ideas to be communicated across the different groups. In this project we have found that the integration of artists, programmers, game-designers, concept artists, and subject matter experts has been invaluable in meeting that goal.

References

Adzima, J.(2001, January 24). AI madness:Using AI to bring open-city racing to life. Gamasutra. Retrieved December 08, 2003 from http://www.gamasutra.com/features/20010124/adzima_01.htm

Boer, J. (1999, January 8). Deer hunter's three-month development cycle. Gamasutra. Retrieved December 08, 2003, from http://www.gamasutra.com/features/19990108/boer_01.htm

Camaioni, L., Ercolani, A. P., Perrucchini, P., and Greenfeild, P. M., (1990). Video games and cognitive ability: The transfer hypothesis. *Italian Journal of Psychology*. *17*(2), 331-348.

Carless, S.(2003, August 8). Marc Laidlaw on story and narrative in half-life. Gamasutra. Retrieved December 08, 2003 from http://www.gamasutra.com/features/20030808/carless_01.shtml

Celnik, P. and Cohen, L. G. (2003). Functional relevance of cortical plasticity. In Boniface, S. and Ziemann, U. (Eds.), Plasticity in the human nervous system: Investigation with transcranial magnetic stimulation. New York: Cambridge University Press.

Doolittle, John H. (1995). Using riddles and interactive computer games to teach problem-solving skills.*Teaching of Psychology. 22*(1), 33-36.

Green, C. S. and Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*. *423*, 534-537.

Keighley, G.(n.d.). The perpetual observer. Gamespot. Retrieved December 08, 2003 from http://www.gamespot.com/gamespot/features/pc/simsonline/

Mayer, R.E. and Sims, V. K. (1994). For whom is a picture worth a thousand words? Extensions of a dual-coding theory of multimedia learning. *Journal of Educational Psychology*, *86*(3), 389-401.

Merzenich, M. M., Wright, B. A., Jenkins, W., Xerri, C., Byl, N., Miller, S., and Tallal, P. (2002). Cortical plasticity underlying perceptual, motor, and cognitive skill development: Implications for neurorehabilitation. In Johnson, M. H. and Munakata, Y. (Eds.), *Brain development and cognition: A reader*. Malden, MA: Blackwell Publishers.

Pillay, H. (2003). An investigation of cognitive processes engaged in by recreational computer game players: Implications for skills of the future. Journal of Research on Technology in Education. 34 (3), 336-350.

Prensky, M. (2001). Digital Game-based Learning. New York: McGraw-Hill.

Rapoport, S. I. (1999). How did the human brain evolve? A proposal based on new evidence from in vivo brain imaging during attention and ideation. Brain Research Bulletin. 50 (3), 149-165.

Shaw, C. A. and McEachern, J. C. (Eds.) (2001). *Toward a theory of neuroplasticity*. London: Psychology Press.

Sterr, A., Elbert, T. and Rockstroh, B. (2002). Functional reorganization of human cerebral cortex and its perceptual concomitants. In Fahle, M. and Poggio, T. (Eds.), *Perceptual learning*. Cambridge, MA: MIT Press.

Microsoft hails "half-life 2" as new benchmark in games for windows. (2003, September 10). Retrieved December 08, 2003 from http://www.microsoft.com/presspass/press/2003/sep03/09-10HalfLifePR.asp

Woodcock, S.(2000, November 1). Game AI:The state of the industry. Gamasutra. Retrieved December 08, 2003 from http://www.gamasutra.com/features/19981120/gameai_01.htm