MACHINES OF PERCEPTION

A Proposal for Interactive Science Learning

Catherine Harrell, March 15, 2010, Draft 1

Abstract

Science requires an understanding of systems: how do parts fit together to make a whole? Unfortunately, many students have trouble visualizing elaborate structures or understanding detailed models. In “Machines of Perception,” an online game for high school biology students, players will learn about sensory physiology by building model perceptual systems from scratch. The game will guide the player through constructing a retina, an eardrum, and other complex structures out of simple parts. By actively building a system, the player will develop a better understanding of dynamic function than they would obtain from a diagram, and they may also begin to see the beauty and elegance of our natural perceptual processes.

The idea originated from a personal interest in human sensory systems, along with a desire to explore educational game creation. I hope to gain experience with interactive design and achieve a richer understanding of how perception works. The main challenges include technical implementation, designing reliable assessment methods, and striking a good balance between fun and learning. I propose to meet these challenges through iterative design: the development process will start with simple low-resolution prototypes, and will gradually evolve into a fully functional 3D system. User testing will be performed frequently to assess the interactive components, and learning studies will be conducted at regular intervals to determine educational outcomes. Learning studies will include qualitative assessments of a player’s progress, as well as comparisons between understanding gained from reading a textbook and understanding gained from playing the game.

Learning problem

In recent years, the practice of science has become increasingly important in American education, as the United States strives to remain competitive in science, technology, engineering and math, collectively known as STEM. Recent science initiatives, including the multimillion dollar "Educate to Innovate" campaign, aim to increase interest and subsequent involvement in scientific disciplines (Chang, 2009).

Science education involves a suite of core skills: in addition to the scientific method, science students learn logical reasoning, cause and effect, and systems understanding. However, "most science curricula found in schools today are descriptive, focused on the laws, theories, and concepts," (Hurd, 1998) and students often have a poor understanding of cause and effect (Perkins & Grotzer, 2001). Many students also have trouble picturing objects in 3D, a skill that could greatly improve their understanding of STEM topics (Eisenberg & Pea, 2008).

The importance of system learning has been emphasized by researchers and educators in recent years, including Harvard's Understandings of Consequence project (Grotzer & Bell, 1999) and recent reports on systems biology:

> Because a system is not just an assembly of genes and proteins, its properties cannot be fully understood merely by drawing diagrams of their interconnections. Although such a diagram represents an important first step, it is analogous to a static roadmap, whereas what we really seek to know are the traffic patterns, why such traffic patterns emerge, and how we can control them (Kitano, 2002).

Without understanding how systems work dynamically and interactively, students struggle to make predictions and determine sequences. These issues are especially important for high school students as they embark on studies of complex anatomy and physiology, as it also applies to introductory physics and chemistry classes. If high school students become frustrated with science at these early stages, they will be less likely to pursue STEM areas in the future.

The overall learning problem can be stated as follows: High school students need an interactive way to practice working with complex systems.

Existing Solutions

Medical illustration has a rich history, from ancient Egypt to the Renaissance to modern digital media. Traditionally, anatomical systems are described through static diagrams and illustrations. Such representations include textbook diagrams (Kandel, Schwartz, & Jessell, 2000) and sophisticated medical graphics (AMI, 2010).

The Bodies Exhibition, an international museum exhibit of real human bodies, brought anatomical illustrations into real-life 3D (Premier, 2008). The use of 3D has the potential to enhance understanding and visualization of anatomical structures. Building physical puzzles has become widespread in classrooms: high school courses may use plastic molecules for chemistry or cell models for biology. Learning by actively designing a structure can have a positive impact on learning: a group of sixth graders improved their understanding of systems by building a model respiratory system (Hmelo, Holton, & Kolodner, 2000).

In recent years, science education has also crept into the world of games. Relevant examples include Fantastic Contraption and Crayon Physics Deluxe, both physics-based puzzle games that incorporate system design. Although both of these examples are two-dimensional, there are several 3D computerized puzzles designed to enhance spatial reasoning (Ritter, Preim, Deussen, & Strothotte, 2000). 3D volumetric displays, while still in development, also have the potential to improve spatial visualization and visual reasoning in STEM research (Eisenberg & Pea, 2008).

For my project, I hope to take advantage of the power of 3D displays in order to enhance systems understanding. Existing game design and usability heuristics will be used to make the interactivity as simple and intuitive as possible. Researchers have devised best practices for including games in classrooms, such as asking students to produce and not just consume, staying focused on learning, and incorporating interdisciplinary skills

(McDaniel & Telep, 2009), all of which can be incorporated into the design of the proposed game.

Design approach

The project is based on a theoretical framework of interactive education. Research indicates that games and other interactive play experiences can enhance learning and memory (Gee, 2007b), especially when the activities engage multiple senses. The role of sensory perception in learning is well documented. Indeed, discussions of play, interactivity, and sensory development can be found in many influential learning theories, including the works of Montessori and Piaget (Montessori & George, 1992; Piaget, 1962).

Montessori describes physical interaction as a precursor to higher cognition, with a special focus on sensory development (Montessori & George, 1992). According to Montessori, interacting with an object and attending to detail can lead to more powerful discernment and observation skills, both of which are useful in science education. The proposed project will encourage interactive manipulation of objects on the screen, and the game will include multimodal feedback such as visual and auditory cues. In order to solve the puzzles, students will attend to visual characteristics, observe changes, and classify objects, all of which require active sensory engagement.

Though Piaget's work deals specifically with children, his principles of play can be applied to people of all ages. "There are individual actions such as throwing, pushing, touching, rubbing," he writes. "It is these individual actions that give rise most of the time to abstraction from objects" (Piaget, 1970). Like Montessori, Piaget emphasizes active experimentation as a crucial foundation of learning. Instead of being taught about physiology through a book or a diagram, students will have the opportunity to play with the objects themselves. Science students in particular will benefit from manipulating the pieces and generating ideas about what will happen next.

The game will be produced through an iterative design method. Due to the highly technical nature of the project, it is important to get the basics right before spending time on the details. Simple prototypes will be tested and revised, beginning with storyboards and "paper prototypes" and gradually advancing to 2D puzzles and eventually complete 3D systems. Because system understanding can apply to many types of models, not just extremely complex ones, testing can provide valuable information even when the systems are still rather small.

Technology

I chose to create a game for several reasons. First, games can be powerful media for learning. "Challenge and learning are a large part of what makes good video games motivating and entertaining," writes James Gee. "Humans actually enjoy learning, though sometimes in school you wouldn't know that" (Gee, 2007a). Through games, students can learn and have fun simultaneously, and they will appreciate challenges instead of rejecting them. Secondly, games have been undergoing an exciting trend in recent years: more people are playing games than ever before, from a wide variety of backgrounds (Juul, 2009). For example, women are playing games more often than in previous years, and different age groups are playing games for many different reasons. With the opportunity to reach virtually any audience, computer games have become an exciting venue for interactive education.

The project will be implemented with Autodesk Maya and Unity 3D. Maya is a modeling and animation program for the creation of three-dimensional objects. The program is powerful and flexible, and it has also been championed as a valuable tool for modeling biological systems (Sharpe, Lumsden, & Woolridge, 2008). Unity 3D is a game engine, useful for adding interactivity and user interfaces to computerized models. Fully compatible with Maya, and also known for its ease of use, Unity will facilitate the transition from a complex model to an interactive puzzle.

Other technologies exist for these purposes; some forerunners include 3D Studio Max, Blender, the Unreal Engine, and Ogre 3D. Since I already have experience working with both Maya and Unity, I hope to spend my time primarily on implementing the game, rather than learning new technologies.

Ultimately, the project will combine the educational value of physical puzzles with the accessibility and convenience of a computer interface. By framing the problem as a computer game, the project will encourage students to experiment and take risks (McDaniel & Telep, 2009). Unlike a physical puzzle, a computerized simulation allows the player to see real consequences to their actions: for example, changing the parts of the eye may impact a simulated stream of light. Students will achieve a more sophisticated understanding of perceptual systems, and hopefully they will develop core skills that will translate to other areas as well.

Anticipated Product

The final product will be a game called "Machines of Perception." The game will include the following components:

3D Puzzle: Models of perceptual systems and their constituent parts will be constructed in Maya and added to the game. The puzzles will be stylized as colorful, cartoony parts, simple and easy to manipulate. The models will allow easy understanding and a clear intuition of how the parts fit together, while maintaining enough scientific accuracy to avoid introducing misconceptions.

Interface: Players will interact with the models through an intuitive user interface, which will include the ability to save and load games, advance to harder levels, and seek additional help. A clean interface will allow the player to focus on the objective of the game, rather than struggling to understand the mechanics. Designing an effective interface is a high priority for the project, and it will allow me to practice creating good user experiences and running successful user tests.

Levels: The player will begin with an easy puzzle in order to learn the basic mechanics of the game (dragging and dropping, clicking on pieces, attending to feedback cues). The difficulty will gradually increase over the course of the game, allowing players greater independence to make choices and think critically. Levels will be indicated at the bottom of the screen, so players will be able to note their progress.

Consequences: Assembling the puzzle in various ways will result in different outcomes, as would be expected from a real biological system. These consequences will be illustrated in various ways, including the distribution of light for the eye, the spreading of sound waves for the ear, and so on. Emphasis will be placed on real-world conditions, like myopia or deafness, and their possible structural causes.

Resources: In addition to the main puzzle screen, the game will also include ways for the player to seek out more information. For example, players can click to find out more about the retina, and the information they learn may guide their building strategy. They may also look at diagrams of similar structures in the animal kingdom (if a player is building a human eye, they may look at animal eyes for reference). These resources will reinforce the game's grounding in real science, and will allow students to practice seeking information and making logical predictions.

Assessment plans and procedures

Many of the assessment methods will be qualitative in nature: students will be asked to describe their understanding of how the eye works after playing the game, for example. They may also be asked to diagram a system themselves, and answer specific questions about what would happen if various parts were changed. It would be interesting to note if there were any qualitative differences between system descriptions by students who play the game, versus students who had only read a textbook chapter. For example, students who play the game may describe general concepts differently, or display different abilities to make predictions and determine consequences.

The Social Issue Games listserv recently discussed ways to evaluate system understanding. Their ideas included asking students to make predictions, asking students to create their own example systems, and initiating conversations with teachers and parents. Game performance can also be used as a metric for understanding (how long does it take a student to complete a level?), although there are a few caveats associated with this approach.

Finally, state and federal standards may offer ideas for how to evaluate educational interventions. Close communication with a high school, such as Palo Alto High, will be useful for preparing the assessment plans and gathering potential users.

Feedback

Frequent user testing will be employed to gain feedback along the way. Small, informal tests will be conducted regularly as the game evolves, with friends or members of the LDT cohort. At critical milestones, I plan to show versions to my adviser and others who may be able to offer detailed feedback.

References

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Milestones and deliverables

March 18, 2010	Proposal draft submitted
April 9, 2010	Project proposal submitted
April 10, 2010	Storyboards complete for interfaces and puzzles
April 12, 2010	Participants for user testing / learning assessment arranged
April 20, 2010	User testing for low-resolution prototype
May 5, 2010	Simple models built
May 15, 2010	User testing for basic 3D puzzle
May 20, 2010	First learning assessment
June 10, 2010	All 3D models built
June 15, 2010	Interface and game refinement in Unity
June 20, 2010	Learning assessments completed
July 1, 2010	Expansion of features and design tweaks
July 15, 2010	Follow-up with high school students
July 30, 2010	EXPO
August 13, 2010	Final report and ePortfolio submitted
August 18, 2010	Master's Project Submission Form

Time Budget

All of these activities will likely take much longer than I think they will, but here are some preliminary estimates:

Research (anatomy, physiology)	8 hours
Building 3D models	20 hours
Adding interactivity and scripting	30 hours
Creating the game interface	30 hours
User testing (various stages)	15 hours
Revision and refinement	10 hours
EXPO preparation	8 hours

Supporters

Roy Pea: My LDT advisor, an excellent source of ideas and feedback, especially since he has previous experience with 3D learning systems.

Scott Klemmer: Professor of HCI at Stanford. I worked with Scott last quarter when I was a TA, and I would love to get some of his feedback on interactivity and UI design.

PlayFirst: I have access to some amazing game designers and developers through my internship. They would be excellent sources of feedback at various stages of prototyping.

Jaehi Jung: I understand that Jaehi is an absolute ninja with Maya software. I would love to get some help from her end as well.

LDT Cohort: Since many of my LDT peers will need design feedback and user testing as well, I imagine we will all be able to help each other. I can also help some of them with web development and design in exchange for user testing time.

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EDUCATION

Stanford University
MA Learning, Design and Technology, GPA 3.7/4.0. (expected 8/10)
BA Human Biology: Neurobiology of Sensation and Perception, GPA 3.7/4.0. Studio Art Minor. (expected 8/10)

WORK EXPERIENCE

GAME DESIGN INTERN, PLAYFIRST, SAN FRANCISCO, CA (01 / 10 – present)
Conducted usability studies, presented ideas and feedback reports, and improved documentation and tutorials for online casual games.

USER INTERFACE DESIGN INTERN, LINDEN LAB, SAN FRANCISCO, CA (6 / 09 – 8 / 09)
Developed XML layouts for new Second Life user interface. Documented and streamlined over 200 advanced features. Designed new windows, revised old layouts, and made valuable settings more accessible to users.

EXPERIENCE DESIGN INTERN, REACTRIX SYSTEMS, REDWOOD CITY, CA (6 / 08 – 8 / 08)
Studied user interactions with WAVEscape, a gesture-based system for games and advertisements. Composed data reports, presented findings to the design team, and developed strategies for better product usability.

ACADEMIC EXPERIENCE

RESEARCH ASSISTANT, RUSSELL FERNALD NEUROSCIENCE LAB, STANFORD, CA (6 / 07 – present)
Honors thesis developing an animated 3D model and user interface for a cichlid fish behavior simulator.

COURSE ASSISTANT, CS147: INTRO TO HUMAN-COMPUTER INTERACTION, STANFORD UNIVERSITY (9 / 09 – 12 / 09)
Assisted professor with lessons, grading, and assignments. Conducted a weekly studio session for students.

PROGRAM ASSISTANT, DESIGN THINKING AND INNOVATION, STANFORD D.SCHOOL (8 / 09 – 9 / 09)
Coached undergraduates through design projects using principles like needfinding, ideation, and prototyping.

RESEARCH ASSISTANT, SYMBOLIC PROJECT ON AFFECTIVE NEUROSCIENCE, STANFORD, CA (6 / 07 – 4 / 08)
Operated fMRI scanner, recruited subjects, and analyzed data about decision-making. Compiled a literature review to inform future studies.

HONORS AND AWARDS

RECIPIENT, HONORS RESEARCH MAJOR GRANT, UNDERGRADUATE ACADEMIC LIFE (6 / 08 - present)
Human Biology Honors Thesis, "Biokinematics and the Animation of Virtual Life."

RECIPIENT, MAJOR ARTS GRANT, ASSOCIATED STUDENTS OF STANFORD UNIVERSITY (12 / 08 – 4 / 09)
"SuperLions: A Graphic Novel." Comic book displayed at campus-wide art show "An Art Affair."

RECIPIENT, HUMAN BIOLOGY RESEARCH EXPLORATION (HB-REX) GRANT, STANFORD UNIVERSITY (6 / 07)
Funding for summer research in neuroscience. Presented two research posters at the HB-REX symposium event.

ACTIVITIES

FREELANCE CARTOONIST, www.catherineharrell.com (2/01 - present)
Produced cartoons, graphic designs, logos and websites for paying clients. Illustrated 4+ children's books and self-published 3 comic books. Contributed to The Stanford Graphic Novel Project and The Stanford Chaparral Humor Magazine.

PEER COUNSELOR, The Bridge Peer Counseling Center, Stanford, CA (12/06 – 3/08)

TEACHING ASSISTANT, Peer Counseling Skills, Stanford School of Education, Stanford, CA (3/06 – 6/06)

SKILLS

COMPUTER*:* Skilled in HTML, XML, CSS, Maya, Adobe Creative Suite, Microsoft Office, and Unity 3D. Working knowledge of Java, C++ and Python.

LANGUAGES: English and Spanish. Studied abroad for 3 months in Madrid, Spain. (3/08 – 6/08)