MASSACHUSETTS INSTITUTE OF TECHNOLOGY

THE COMPARATIVE MEDIA STUDIES DEPARTMENT
IN COLLABORATION WITH MICROSOFT
PRESENTS
A GAMES-TO-TEACH PROJECT

SUPERCHARGED!

MAY THE ELECTROMAGNETIC FORCES BE WITH YOU

DESIGN DOCUMENTATION

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DESIGN HISTORY

Version 1

March 5, 2002. Kurt Squire. Started entering brainstorm notes into design document.

1. Listed Philosophical Goals / Objectives.
2. Did some stuff on pedagogy.

Version 2

March 9, 2002. Elliot and Robin presented working design to group. Feedback incorporated into document.

Version 3

April 11, 2002. Wally made a few minor changes and clarifications to the ‘Gameplay’ and ‘Game Overview’ sections, and completed the ‘Technical Information’ section.

Version 4.1

April 24, 2002. Robin consolidated all recent changes made by Wally and John Belcher as well as editing significantly the character, gameplay and single-player level design pages.

Version 7.1

Kurt added an intro, made some other minor tweaks.

SUPERCHARGED!

You enter a physics classroom. In front of you stands a 60-something professor, droning monotonously. Looking down, you notice a comic book that someone has slipped into your papers. Hmmm. You pick it up, inquisitively. On the back, you notice a pair of flimsy cardboard 3D glasses. You look from side-to-side, trickily.….

Before you even realize what happened, you're sucked into a surrealist world of pulsating lights and sounds. You spin to the left and bank off of an invisible wall, narrowly missing a collision with a powerful magnetic field. Pulsing lights fly by you as you navigate a small blue glowing pod through a drippy, surrealist space populated by flashing lights, humming sounds, and small furry creatures, called Fizzgigs.

As it turns out, Fizzgigs are native to this surrealist electric space. They have been enslaved by your evil professor, and are being enslaved to help the professor in his evil plots. You quickly realize that these cute, but occasionally annoying creatures may be your biggest hope for getting out of here alive. While they cannot drive your pod (they can't reach the pedals), they *have* grown up in this counter-intuitive world of electric and magnetic interactions. Together, perhaps you can save them.

SuperCharged! is an action racing game that is designed to give players an intuitive understanding for introductory E&M reactions. Research in teaching Electromagnetism has shown that students have a very difficult time understanding how electromagnetic forces interact. The laws governing electromagnetic forces, such as Maxwell's laws are very counter-intuitive, and students have little real frame of references for understanding how these forces interact. John Belcher, who teaches Electromagnetism at MIT explains how even when students do pass tests showing that they've "mastered" Electromagnetism, they frequently lack any deep understanding of how these forces interact.

Earlier projects, such as Science Space, used headset VR displays to teach these same principles. The advent of 3D gaming technologies makes this kind of 3D immersive experience feasible on a $99 PlayStation. Working with John Belcher, we've designed a 3D interactive racing game where players learn how electromagnetic forces interact by placing them so that they are propelled through space. Players are sent through wires, propelled through electromagnetic fields, and even forced to navigate through a level after being blindfolded by the evil professor. Through playing *SuperCharged!*, players may not learn electromagnetic formulas, but they will develop an intuitive sense for how electromagnetic interactions work that will serve them as they learn these formulas in a through extended study.

GAME OVERVIEW

E&M: The Development Backstory

The Electromagnetism game is a collaborative effort between members of Games-to-Teach and a group of forward-thinking MIT physicists. In November of 2001 we first met with Professor John Belcher, one of the main architects of the TEAL/Studio Physics Project, and Andrew McKinney, the TEAL/Studio Project Manager. TEAL, short for Technology Enabled Active Learning, advocates a new way to teach introductory physics, especially Electromagnetism. Stressing active student engagement with the material and advanced technological teaching aids, TEAL is one of many projects sponsored by the MIT Council on Educational Technology. TEAL is in part a reaction to the high failure rate of students in undergraduate lecture-style physics courses. But in addition to helping students at the lower levels, the TEAL approach improves the learning outcomes of students at all levels.

The student-centered, technology-enhanced pedagogical principles underlying Professor Belcher's work on the TEAL curriculum led us to initiate a collaboration. Experimentation, discussion, reflection, visualization and assessment, as well as a firm belief in the potential of advanced technology to aid in teaching math and science are priorities that fuel both projects. Games-to-Teach is interesting to the Physics Department because of its validation of digital gam-based learning and its insistence on developing games with strong narratives, something outside the scope of most advanced physics courses. Belcher writes in an article for the Annual MIT Physics Department Newsletter, "In considering the description of the TEAL/Studio course format … keep in mind that one of the overall goals is to set up a structure that engages the students more deeply so that they come away from these introductory courses with more of an appreciation for the beauty of physics, both conceptually and analytically." ("Studio Physics at MIT", p.59-60). Professor Belcher sees games as a way to help lift complex science material out of the textbook and into the real world, where students can gain a clearer appreciation for its pervasiveness and its elegance.

Games-to-Teach believes our game will immerse players in this opaque science so that they come to "see" it intuitively, so that it begins to make sense visually in their understanding of the world. This would be a great accomplishment for both Games-to-Teach and Professor Belcher's team, as current teaching methods drive students to memorize formulas and solve problems by rote, remembering little beyond the end of the term. During initial discussions of possible game adaptations of EM course material, GTT researchers agreed that one of the greatest benefits a game could provide would be dramatic, stimulating representation of naturally invisible phenomena. The ability to explore an environment populated by charges and fields, and through trial and error develop an understanding of the laws determining their behavior will foster deeper understanding and greater retention of information.

Early conceptualizations of the EM game drew heavily on computer animations created by Belcher and McKinney which represent in various ways the behavior and motion of charges and their electrostatic and magnetic fields. By observing the behavior of the charges as they move in response to various forces transmitted by the fields, students are able to intuit complex concepts that may hold little interest as figures on a page. However, since then, we have decided that a racing game that might leverage the interactivity of games could be even more compelling. Because the laws of Electromagnetism are very tied to motion, they could make for an excellent racing game, where the player's movement was controlled by the laws of electric and magnetic forces.

Both Games-to-Teach and the MIT Physics Department believe strongly that the partnership we have formed and the work we are doing will result in a unique type of game experience, and a welcome bit of help for all levels of students taking the course, in particular the less mathematically minded.

GAMEPLAY

Setting

The cut scene which introduces the game takes place in a university classroom, but once transported, the player spends the rest of the game in a series of psychedelic 3-D environments. The game universe belongs to the Fizzgigs, a species of furry, loyal creatures, who worship the player as their savior from an evil enemy. Setting aesthetic changes drastically as each level is completed and Fizzgigs are either rescued or lost. Player excitement will grow with the increasing abstraction and beauty of the level settings, and player immersion will lead to learning.

Each level is designed to demonstrate the interaction between charged particles using a different representational mode. As Professor Belcher’s team at MIT has shown, field lines may be animated in any number ways. By varying the means of representation we will be able to constantly defamiliarize the player and encourage her to engage with the science again and again.

Following are some of the ways we will animate the field lines:

1. Colored Lines
2. Rays of Light
3. Vapor Trails
4. Color Hue
5. Volume
6. Pitch
7. Interactive Music (e.g. distance to given particles represented as corresponding tones)

Failure States

The game ends when the player runs out of energy. A Player’s energy will be monitored via the Life Meter.

Win States

A player wins when she has completed all levels of the game and saved the Fizzgigs from the evil professor. More specifically, levels are ‘won’ when obstacles have been surmounted by spatial navigation, world interaction, or object acquisition; goal locations will be clearly marked, and in-game reminders will point the player toward her eventual goal state.

PHILOSOPHY AND DESIGN GOALS

An immersive, interactive 3D game based on principals of Electromagnetism would leverage gaming technology to support understanding of this science, which is difficult to learn.

Mastering the core principals of Electricity and Magnetism is notoriously difficult. Dede et al. write "Electromagnetic fields are three-dimensional, abstract, and have few analogies to learners' everyday experiences. As a result, students have trouble understanding the relationship of abstractions about electric fields to phenomenological dynamics." Dede et al. argue that learners often confuse the concepts of force and energy or fail to understand how electric charges interact with test charges. Because students lack real-life referents of electromagnetic interactions, intuitive metaphors for understanding the interactions, or environments for testing their thoughts and assumptions about how charges interact, students frequently develop and retain impoverished understandings and misconceptions of Electromagnetic phenomena. Communicating such content through a game space makes intuitive sense.

A game on Electromagnetism could give learners opportunities to interact with Electromagnetic phenomena. Learners' experiences manipulating charges and interacting within Electromagnetic worlds could be the basis for developing qualitative understandings of these phenomena. Research (Dede et al., 1999; Reimann & Spada, 1996; White, 1993; White & Frederickson, 1992) suggests that such qualitative experiences are the foundation for more scientific, abstract understanding.

Fantastic, surrealist environment
Over the last ten years, many American game designers have become increasingly interested in providing "realistic" graphics. We believe that there is an array of untapped aesthetic areas to explore in creating surrealistic, fantastic, or "other-worldly worlds". Most game designers have assumed that game spaces should roughly model reality in order to provide a intuitive feel to the gameplay. Why not create a game where surprise is built into every new interaction in the environment? Poole (2001) argues that game designers have mistakenly strove for realistic environments, when in reality, it is consistent behavior that is desirable.

Common Questions

What is the game?
EM is a first person racing / maze game in which the player navigates through abstract environments by manipulating charged forces. The goal is to save a species of fuzzy creatures called Fizzgigs from the evil Physics Professor who wants to enslave them and take over the game world.

Why create this game?
Previous educational design experiments in Electromagnetism (e.g. Dede, et al., 1999) show that experiencing scientifically accurate models of fields, interacting with multi-sensory cues of normally imperceptible phenomena, and engaging with these phenomena can be powerful ways of learning Electromagnetism. Maxwell's laws for example, are simple, navigationally oriented

rules that translate into a natural set of game rules. Finally, the game will take advantage of the stunning and beautiful nature of Electromagnetic field visualizations.

Where does the game take place?
The game takes place within a series of abstract, 3-D worlds. Each level takes place within a spherical dome and contains surrealist depictions of the objects commonly found in Electromagnetic texts.

Describe the Controls
The player controls her avatar moving through space and places charges in the environment to propel herself. On the PC, the player uses the mouse to control view, and moves in part by changing her net charge as she moves past fixed sources of charge and magnetic field embedded in the scene. The player can also shoot charges that are attracted to other moving "friends" and "enemies" in the scene saving them or destroying them if they connect. The left button fires positive charges; the right negative charges. On the console the game uses controls similar to Halo. The left joystick controls the view. The right joystick controls the direction the particle will be fired. This targeting system is relational to the player, so that left always shoots the particle to the player's left (as opposed to along a fixed x, y, or z axis. Pressing the right trigger will emit a positive charge; the left trigger emits a negative one. How far the object goes away (which axis that is depends on the player's view).

What is the main focus?
The main focus is navigating your pod through space, conserving your life supply and getting from level to level in order to rescue the Fizzgigs and banish the evil professor.

What's different?
Previous educational experiments in this area allowed users to manipulate charges and electric and magnetic fields, but not within a goal-driven narrative context. Formative research on Maxwell's universe (Dede, et al., 1997) suggests that players have come to expect game-like experiences in interactive digital environments. Unlike most shooter / maze games, the player moves not only by directly controlling her character, but by manipulating her properties in response to the environment so that she is attracted or repelled in various directions.

Who is the target audience?
The target audience is high school students, introductory college students and casual gamers. Because the game offers opportunities to gain intuitive qualitative understandings of physics, we believe that it would be attractive in schools, formal, and casual gaming environments.

What will people learn through playing this game?
Players are learning the basic laws of Electromagnetism (see Science Content).

How will people learn through playing this game?
Players will learn actively through repeated interactions with the world. Similar to ecological notions of learning, the player will eventually become attuned to the environment so that interacting with objects embodying EM laws will become intuitive.

Give a number of verbs that describe the gameplay.
Dodging, aiming, spinning, bouncing, ricocheting, strategizing.

What platform are you aiming for?
X-Box

Describe the look and feel.
EM has bright colors and a very surrealist feel, similar to games like Rez or FreQuency but using the color palette of a game like Giants. However, we want to “soften up” the game feel in order to make it more appealing to a broader market. In particular, the Fizzgigs provide players an opportunity to relate to virtual characters and build relationships in the game world.

Why is the game fun?
EM draws on the speed and thrill of racing games, while involving the strategy of golfing games (without their often-stultifying pace) and shooters. Players can choose to play the game very quickly or relatively slowly, depending on play styles. The surrealist game environment and fantastic levels are a big draw for shoppers browsing the shelves at a game store or students playing the game in a curricular context.

SINGLE-PLAYER GAME

The Story:

A freshman girl walks down a long university hallway, a massive physics textbook under her arm. She looks glum. She drags her feet and pauses to adjust the book. When she arrives at her classroom she opens the door to a huge lecture hall.

In the front of the hall an evil looking professor drones on about Electromagnetism, scrawling lengthy indecipherable formulas on the board. The girl sits down, opens her textbook, and stares at the numbers on the page. They make her eyes burn. She glances up at the teacher, reaches into her bag and pulls out a comic book, *Fizzgigs SuperCharged!*.

We see in detail a page of the comic book. It has a surreal, abstract design. A furry species of creatures called Fizzgigs inhabits the spacious 3-D world in which electric and magnetic fields animate in vibrant ways. An evil man who looks quite like the professor is trying to enslave the Fizzgigs in order to take over the EM world. They are looking for help.

The Leader of the Fizzgigs, Zap, addresses a massive assembly of buzzing creatures. He holds up high a pair of magic glasses, beckoning The Chosen One to come to their aid. Suddenly the girl finds a pair of glasses in the fold of her book. Without hesitation she puts them on.

This action sucks her into the game world, at which point the player takes over. The player enters the equipment room where she is instructed to design a pod inside of which she will travel through the game world. The pod she chooses is bright green, smooth and glows with energy. She chooses to give it a positive charge. Next the player is shown the controls and tools she will use in the game.

First there is the Life Meter. In order to stay alive in the game the player must conserve life energy. If your Life Meter gets to zero you die -- that is the failure condition of the game. Two main actions deplete your Life Meter: hitting a wall and using force for propulsion. These features train the player to strategically place charges in the environment to generate for through attraction and repulsion, rather than relying on propulsion.

Another feature of the game interface is the multiple perspective windows. The player default perspective is first person, and there is a toggle button that will allow the player to switch to third person. The game world is 3-D but there will be a second window which shows the action in 2-D. This will help in positioning charges especially in later levels.

The Levels:

<u>1st level</u> (EM golf)

The first level is meant to be extremely simple, and the level environment is relatively free of detail. The Chamber, (as we will call the levels), is a massive sphere inside of which is 3-D space. It's black - all the player sees is the outline of the sphere, and then one red circle glowing. This is the end point, the escape hatch into the next chamber.

The player start off the level shackled to a wall. She must push a button on the controls to release the pod into the world. But she will find that pressing the release button without placing charges along the course will send her pod flying into a wall, depleting life supply. The player must learn to mark spots where she wants to position positive and negative charges into the world and shoot them there with her fire button. In this way she can chart a course toward the hatch.

The firing button shoots the charges and a toggle switch gives the ability to make them positive or negative. The 2-D window helps the player correctly position the charges before firing them. Each time the layer releases the pod and fails to reach the endpoint the level is repeated. In this way the player begins to master the controls and understand the dynamics of Electromagnetism world.

The glasses give the player the ability to see electric and magnetic fieldlines around charged objects. The player learns in this simplest level what the field lines will look like and how they will behave. This visualization allows the player to better understand the interactions between her pod and the charged objects and walls, and thus begin to intuit the science. As the pod draws near a charge, animated field representations will emanate, growing stronger as the charge gets closer. The aesthetic representation of the fields will take various forms in later levels, from the simplest lines to dense iron filings to psychedelic dots and arrows. Color will be intense, contrasting with the blackness, and representing the beauty of the forces in question. At this stage the player is not able to see the field lines emanating from her pod, but in future levels, once points have been gained by rescuing Fizzgigs, she will win this crucial ability.

<u>Level 2</u>
Once the player attains the red hatch he is sucked into the next chamber. After the player breaks free, the evil professor confronts the protagonist. "You fool! Thinking that you had the strength to survive in this world. You have no idea what you're up against."

The Fizzgig responds, "You, too, huh. Don't listen to him. We need to make it out of here alive. If you can break me free from this wall, I'll show you amazing things..."

Still in a cut scene animation, the professor throws a book at the player, slamming him against the wall. On the dashboard of the pod appears: "Break free of chamber. Rescue <Fizzbee's Name>.
In this chamber the player finds himself again shackled to a wall, but this time he finds Zap next to him. Zap has been shackled to the wall by the evil professor. The player must unshackle him and bring him into the pod. Zap from there on in is the player's loyal, furry, squeaky-voiced mentor, providing advice on how to advance in the gameworld.

The purpose of the second level is to teach the player about the propulsion feature. The game environment looks quite similar to the first and there are almost no obstacles. As in level 1, it is necessary to carefully position charges in the field in order to shoot in the right direction. But as opposed to the previous level in which the game shot you out into the world, here the player is given the ability to self-propel. An important lesson in energy conservation starts here. If the player relies too much on propulsion to make his way around the level he will use all his life force. The player learns to use propulsion carefully and count on the placement of charges.

The second level will also introduce the power-up. Power-ups will most often be found near the end of a level, in view of the escape hatch. The power-ups are Fizzgigs in peril, and each one the player clicks on is saved from the evil professor. Saving Fizzgigs adds life to your Lifemeter. In more difficult levels, power-ups will be quite challenging to attain, either guarded by the evil professor or stuck inside a complicated maze of barricades.

Level 3

Level three aims to combine the skills learned in the previous two in a more complex environment. This means there will be more barriers and a slightly faster pace, but the gameplay will draw on the previous levels. This level will solidify the player's mastery of the controls.

At the end of level three the player meets the Professor in the chamber. The Professor adopts a negative charge, pulling the pod toward him. In order to escape Zap instructs a change of the pod's charge. Switching with the +/- toggle to negative, the player may repel himself away from the professor. "You can not escape me," the professor warns, "I know where your seat is." At this point the player is thrust into level four.

Level 4

The fourth level is inspired by the classic edutainment experiment, *Donald Duck in Mathematics World*. Here the player enters a world of floating formulas and experiments. The player must carefully navigate the space, helped along by Zap, and get up close to the experiments. For instance at one point the player could find herself bumping up against a magnet dropping though a charged copper wire, illustrating Faraday's law. The field lines are dense and complicated. In another, a particle moves along a charged rod, illustrating Maxwell's Laws. This level is the first of a number of "textbook" chambers we will create. Each one will increase in difficulty as the complexity of the experiment increases. By being able to see the behavior of the field lines in fundamental examples the player will learn to contextualize and deepen their memorized knowledge of textbook formulas.

Additional Level Design Ideas:

Level (or concept translated to cool game moment) X: In the course of her journeys, the player has to cross a chasm of an intolerably strong electric field. There are two pieces of insulting material that might make a bridge across, if only they were connected. Each piece is attached perpendicularly to a conducting wire. By applying an electromotive force to one of the wires, the player can cause the two wires to move together, and a bridge will form. This is classic video-game logic that will illustrate the force between two parallel current-carrying wires; the mechanics can be explained by Zap via an obviously suggestive cutscene.

Level X+1: The player's ship is outfitted with a special device by Zap's team of scientists, because only the player can solve a problem of life and death for the Fizzgigs, or whatever they’re called. A remote outpost of theirs has been sealed off by the evil professor, who has surrounded it with a dangerously charged conducting shield. Drama of some kind can be added through a cutscene depicting the tragic demise of several adorable Fizzgigs who try to get through the shield to no avail. Zap will instruct the player on the use of the device, which is basically a self-deploying pylon that, once fired, will extend itself from the shield to some nearby ground, effectively disabling the shield. This is an example of a variety in mission from the usual “dodge things, exit level” objective that can be used to provide incentive for the player to care.

Level X+2: Among other obstacles, the player must negotiate a closed door. The door is controlled by a circuit that the player cannot directly control; its only wire consists of an insulated coil. However, close to it is another, uninsulated coil that the player can induce an electromotive force in with her fired charges. This current will induce a magnetic field whose changing magnetic flux will, by Lenz’s law, induce an opposing electromotive force in the other, entirely separate coil, opening the door. This illustrates the principle of mutual inductance, which is notoriously misunderstood by students. This concept that the environment tries to resist changes in magnetic fields by producing opposite fields whenever possible (Lenz’s law) is one of the most important in the field, but would benefit greatly from demonstration in a concrete, player-controlled scenario.

USER SCENARIOS

General Outline

Time	*Events*	*Decisions / Experiences / Emotions*
1 Min.	Player loads game, views animation	Players feels swept away into surreal alternative universe. Player feels sense of whimsy and play.
5 Mins.	Player enters ship, learns controls	Player is thinking pretty hard, trying to adjust to the controls. The controls are relatively simple, akin to most flying games, so experienced gamers should learn them almost immediately, and novice players should be adept with them within 15 minutes.
18 Mins.	Complete First Level.	Player experiments with controls and moves around the universe. The first challenges are to learn the controls and move throughout the environment. Because it is her lack of knowledge for how particles interact that prohibits her movement, she should quickly start to see how this could help her learn Electromagnetism.
20 Mins.	Player meets Fizzgigs	Player learns that there is more to the game that just flying. Players become more emotionally invested in the game. Players interested in characters, relationships, and nurturing creatures become more engrossed in the game.
1 session	Player has completed at least 1 level and had significant interactions with the Fizzgigs.	Player feels sense of accomplishment completing level, curiosity about these Fizzgigs, emotional connection to their plight, and curiosity about what is in store on the next levels.
5 hours	The player must save the Fizzgigs' families	The player has a sense now that he / she is the chosen one. She must save the family of Fizzgigs from impending doom.
20 hours	The player defeats the professor	Feelings of accomplishments

User Scenario 1

Kelly, a 18 year old senior in Physics II sits in class. Mr. Stevens, her Physics teacher introduces the game. "Electromagnetism is very hard for many students to grasp. The behavior of electric charges is often counter-intuitive; particles behave in peculiar ways, if you don't have a good feel for how they interact. Now, your textbook provides formulas for describing the behavior of these particles, and I've downloaded some very nice animations of particles from Dr. John Belcher's website. However, it's still pretty tough to get a handle of how these particles behave. So, we're participating in this experimental program, where we'll be learning more about electric charges through a video game, *SuperCharged!*"

Several sleepy-eyed seniors raise their heads. A murmur starts throughout the room. "A video game?"

"Figured that would wake you guys up. Yes, a video game. It's a racing, flying simulation game where you adopt the properties of a charged particle. We hope that it will help you get an intuitive sense for how these particles behave."

Unlike many in the class, Kelly seems less-than-enthusiastic about this idea. "Playing a video game?" she thinks. I hope that this helps me with the AP test. That's why I'm in this class. I could care less about 'intuitive understandings' or charged particles. Just give me the information and help me with the test. Oh well, Stevens is a pretty serious teacher, so he probably wouldn't do this unless it works."

Kelly sits at the computer and loads the game. Stevens talks above the noise of the lab, "The goal for today is to learn the controls, and get past 2 levels. Anyone who gets past the first 4 levels gets extra credit. And, helping is allowed. Yes, you heard that right, please help each other as much as you want."

Kelly loads the game and sits back while the cut-scene plays. She smirks at the playful depiction of the surrealist world, noting ties to books like *Alice in Wonderland*. Good to see that the designers had some creativity and a sense of humor," she thinks. Finally, after about 45 seconds, she's in control of the ship. Kelly scans the screen, noting the 2D window in the lower right hand corner. She places her hand on the mouse, and notes that the screen view changes as she moves the mouse. Outside the window, the world looks bold, inviting, colorful, and worth exploring.

First, the Life Meter begins to glow. She moves her mouse over the life bar. As she move the cursor from the window to the dashboard, she notices that it changes from a circular cross hair type aiming mechanism to a pointer. As she "mouses over" the meter, text appears. "In order to stay alive in the game the player must conserve life energy. Two main actions deplete your Life Meter: hitting a wall and using force for propulsion. If your Life Meter gets to zero you return to the beginning of the level."

Next, the two particle meters (+ / -) glow. Kelly mouses over them. The following text appears: Although you can move using propulsion, you'll notice that your energy runs out really quickly.

Your best way to move fast and efficiently is through firing charges that attract or repel you. You have two kinds of charges: positive and negative charges. Play with them on this level to see how they work.”

“Great,” Kelly thinks. “Seems simple enough. I hate games that are too complex.” Kelly also starts to see how this program might actually help her learn the behavior of particles. Well, I’ll keep trying, Kelly thinks.

Kelly tries pressing the mouse button, and out shoots a negative particle. Her ship rocks a little, but doesn’t move. Kelly stops and thinks…well, hmmm…if that’s a negative particle, and so am I, I would think that it would push me back. She looks down to her right, and notices a small number gauge. Hmmm…it shot the particle out 58 units away from me…maybe I should try something closer. She holds down the trigger a little less. This time, the particle emerges right in front of her, and her entire ship shakes violently. “Whoooooooaaa. Ok. Now I see.” Kelly laughs and tries the right mouse button this time, and shoots out a charge that draws her from the wall and propels her across the room.

User Scenario 2

The player solves the first puzzle. Player walks into the temple, looks around, feels in awe at surroundings. Player sees bit of light and realizes that she needs to refocus it to illuminate the room. Player checks lenses…asks a friend sitting at nearby computer for help.

GAME CHARACTERS

Overview

Characterization in *SuperCharged!* plays off the stereotypical disdain that often exists between student and science teacher. The Player is heroic, intrepid, masterful, the Fizzgigs brave yet dependent, and the Professor purely evil. Friendships develop in the game between the player and the Fizzgigs, especially Zap and Zap's family, and so does the player's desire to protect their world from ruin.

The Player

A typical student thrown into an atypical situation, the player rises to the challenge with ingenuity and poise. When we meet her in the hallway she is tall, dark haired and confident. She is about 18, and relatively fearless. She puts on the glasses without thinking first. She lives for adventure. In the game world the player also demonstrates competitiveness and kindness toward the creatures she has been chosen to save. The player's voice is assured and strong. There is one weakness, which becomes important in later levels of the game. The player becomes blind when she sees too many Fizzgigs die, and she becomes deaf when she hears too many scream. The player must work to avoid those situations.

Zap

Zap is quite a cute little creature, though his numerous children are even cuter. Zap becomes central to the game as he acts as the player's mentor. Zap's large family often counts on the player for protection. Differentiated by a shock of red hair, these familial Fizzgigs drive the narrative through the gameplay.

The Professor

The sinister Professor is the epitome of evil. How else to describe a teacher of physics! Driven by a lust for power and control, the Professor will do anything to take control of the spectacular world of visible EM phenomena. Lanky with hooded eyes and a long beard the Professor haunts each successive level seeking to destroy the player's craft and enslave Zap forever.

Enemies and Monsters

The professor has an entire cadre of enemies and monsters at his disposal. These are mostly taken from the E&M textbook, and include canonical examples such as magnets, handkerchiefs, etc.

TECHNICAL INFORMATION

Immersive Graphical Environment

The gameworld is a 3D space, photorealistic in quality but varying in its degree of abstraction. The world will contain physical features at various levels of scale, from arbitrary point charges floating through atoms-wide charged rings to abstracted real-world examples (the silk handkerchief/rod demonstration of static electricity springs to mind, as does a magnet moving through a current-carrying ring). The interface will be simple, with meters representing life force and charge; but as mentioned before, the notion of superimposing layers of information on the navigation window falls out of the narrative's metaphors of visualization.

SuperCharged! can be modeled with most commercially available 3D gaming engines. The primary challenge will be adapting the game engine so that the particles behave in accordance to the properties of charged particles. Because giving players an intuitive feel for the behavior of charged particles is the primary goal of the game, it is essential that the engine be created to render the behaviors of charged particles realistically. Dr. John Belcher has the equations for these models, but we would need to integrate them into the game engine. Fortunately, these laws are all known relationships that have already been quantified, so coding them shall be relatively easy.

A second technical challenge will be in deciding what level of fidelity to portray the visualizations. Dr. Belcher's visualizations are computationally intensive, and we will need to make trade-offs in fidelity and playability.

We feel that it's important to provide multiple visualization schemes for the concepts presented in the game; the ability to separate the essential data presented in a problem from its representation is a vital one that video games seem uniquely poised to take advantage of. From a graphical standpoint, then, the game will fall somewhere between the psychedelic abstractions of *Rez*, the view-switching power of a 3D modeling program, and the freedom-of-movement of *Descent*. Rendering-wise, little new technology is called for; the innovation will come in the area of interface and interactivity.

Sound as Information Conduit

The aural channel is the most underutilized information pathway in games; yet today's sound hardware offers unprecedented control over a game's audio environment. For our purposes, spatialized sound, combined with the intuitive qualities of musical shapes, will be used as an alternate 'visualization' method. It is a simple metaphorical leap to represent distance to a point, for instance, as the volume of an individual musical note. Three such sources arrayed in space readily form a chord; the sonic characteristics of the chord then change as a player's location shifts relative to the points.

From this principle we can move to other aural metaphors; in one level of our game, a darkened space might require the player to navigate entirely by sound, with a 3D audio system representing the relative strengths of point charges by their pitches or timbre (there are already plenty of musical precedents for mapping the width of vibrato, for instance, to the intensity of a note or passage). From an educational standpoint, mapping a concept onto multiple representational schemes makes sense; for experienced gamers accustomed to entirely ancillary sound effects, this offers an attractive *gee whiz* factor. And the uniqueness of a sonic-navigation challenge will hopefully inspire greater engagement on the part of all players.

Novel Visualization Techniques

From an interface standpoint, we foresee a fairly simple screen; however, because the subject matter of the game is a set of mathematical relations -- and because a major problem facing teachers of this material is the difficulty of representing multiple fields of 3D information on a 2D medium, i.e. the blackboard -- the ability to combine multiple datasets in transparent ways is a central one for our program. Taking the eyeglasses metaphor from the game's story, we feel that a rapidly-switchable system for overlaying views of the world will be an important feature. A level in which, for instance, magnetic fields are represented as elastic bands (marking out paths, as in the common 'iron filings' method of showing a field) should be switchable to a view of rapidly-moving test particles indicating direction through motion.

Of course, this isn't simply an experiment in interface design; manipulating the interface should have the dual effect of both enabling the player to succeed (both more often and in new ways) and making clearer the link between curricular concepts and gameplay aspects. These visual-interface-design issues are to a large degree already-solved problems; however, seamlessly blending gameplay dynamics and mathematical representations has not yet been done completely successfully (else we'd have no need of *SuperCharged!*).

Evocative Interaction Model

SuperCharged! asks the user to interact with the world in slightly backward fashion: rather than moving through space and affecting it independent of the character's state (as in a typical first-person shooter), the player makes changes to the world's basic qualities, which affect her ability to navigate through it. Since an object of the game, from a pedagogical standpoint, is to impart understanding of a system's effects on a 'test particle' (in broad terms, an avatar with set qualities), it makes sense to structure the player/world interaction around a more direct manipulation of the rules. But the fast pace of a racing game can still be maintained, in spite of the increased complexity of this model (watch the string of various rapid actions in a frenetic passage in *Deus Ex*, for instance).

Straightforward Adaptation to Multiplayer

Though we envision *SuperCharged!* primarily as a single-player game, it maps readily to a multiplayer experience. The attraction of a multiplayer game would be different from that of the single-player version, of course; increased tempo combined with the deliberately constrained style of gameplay would, we think, produce a compelling experience quite different from a more scattershot model such as *Quake*. Real-time strategy games show that multiplayer games can keep up a brisk pace while still engaging players at both the tactical and strategic levels; the notion of 'turning on' physical laws over time (moving from the concept of an electric field to EM waves, for instance, or 'enabling' the concept of induced magnetic fields as an additional gameplay wrinkle) could make for a multifaceted single-player and multiplayer experience, given how closely the player's game-state (closeness to victory) and the characteristics of the gameworld are tied.

WORLD EDITING

SuperCharged! features a full level editor, allowing motivated players to design their own challenges. The level-editor is be available through a menu in the regular game, so it accessible to everybody. Level designers are presented with a large three-dimensional grid, representing the game space. By navigating through this space with the keyboard, the designer can make informed decisions regarding the location of the entrance, exit, and obstacles of each level. With a drag-and-drop palette of options and items seen throughout the regular game, a designer can truly create a unique interactive challenge. For more inexperienced level designers, the opportunity to explore the regular game's levels in the editing environment may be helpful and very informative.

The very process of level design and creation is challenging, as a designer must understand the world (and physics) of *SuperCharged!* In order to create a well-balanced, exciting experience. Since the editor allows for so much freedom and creativity, the key to a first-rate level will be using the editing tools to create a demanding environment with a limited number of solutions.

Player-composed levels are playable on their own, and can be strung together with a narrative to permit total creativity. Thus, designers can work by themselves or with a group to create entire worlds. Levels and worlds are modular, so that they can be easily traded between players, on disk or via the Internet. Additionally, instructors can assess students' understanding of the *SuperCharged!* concepts by requiring level design in lieu of homework or an exam.

Level design will increase the replayability of *SuperCharged!* since it gives players an opportunity to think creatively, while expanding the game's world for themselves and all *SuperCharged!* players.

SCIENCE CONTENT

Overview
The starting point for all electro-static interactions is that between two charges such as two electrons, or between a protron and an electron. Electric fields contain energy and transmit forces between the two charges that leads to changes in the charge's motion and energy. This game allows the player to explore these interactions in 3-D space, and compare an active interpretation of these equations with standard text-book values.

Content
Charge, Field and Potential
Insulators and Conductors
Coulomb's Law and Field and Potential of Point Charges
Fields and Potentials of Other Charge Distributions
Spherical Symmetry
Cylindrical Symmetry
Gauss' Law
Electrostatics with conductors
Capacitors
Dielectrics
Current, Resistance and Power
Kirchhoff's loop law
Ohm's Law
Forces on Moving Charges in Magnetic Fields
Torque and Force on Magnetic Dipoles in Magnetic Fields
Biot-Savart Law and Ampere's Law
Electromagnetic Induction
Faraday's Law
Lenz's Law
Maxwell's Equations
Electromagnetic wave

Resources
The design team has worked closely with Professor John Belcher and his team in the Physics Department at MIT to design this game.

Please visit Professor Belcher's home page at: http://web.mit.edu/jbelcher/www/
And his page on teaching Electromagnetism with advanced technologies:
http://web.mit.edu/jbelcher/www/anim.html

View "Magnet Falling through a Ring with Non-zero Resistance" (700k - QuickTime Mov):
http://web.mit.edu/course/urop/8.emfields/Public/animations/fall_far.mov
View "Point Charge Attracted to a Charged Sphere" (900k-AVI):
http://web.mit.edu/jbelcher/www/att.html

PEDAGOGICAL APPROACHES

Overview

Electromagnetism has traditionally been difficult for advanced high school and college physics students to grasp and truly understand. Students struggle with the concepts for many reasons, but three of the most common are:

1) Many of the laws are counter-intuitive:
   Students approach new topics with preconceptions of how the world works, and use the new knowledge to build upon these notions. Since EM laws work in a way opposite to the preconceived ideas of most students, many physics students fail to retain or understand the information they are taught. (How People Learn: Bridging Research and Practice, 10) In fact, while some students may be able to memorize key concepts for the purposes of answering test questions, they will most likely revert to their preconceptions soon after.

2) This science is not explicitly visible in students' everyday interactions in the world around them: Unlike many concepts in physics, students cannot directly see the consequences of electric and magnetic phenomena in their daily life. Thus, students do not develop an intuitive sense, resulting in a greater struggle for understanding.

3) Instructors cannot give their students direct experience with science like Maxwell's laws: Maxwell's laws involve complex phenomena that can only be depicted abstractly, so instructors find it difficult to convey the concepts to their students via direct experience examples and demonstrations.

SuperCharged! is a unique approach to teaching Electromagnetism, and an attempt to overcome the three challenges stated above. EM-Urgency combines interactive gaming technologies and creative 3D displays to create a virtual world built on the physics of Maxwell's laws. This world will provide an environment that will enhance the learning and intuition of students, as well as motivate them with engaging, goal-oriented scenarios.

In the early 1990s, researchers at NASA and George Washington University collaborated to make "ScienceSpace", a project that leveraged virtual reality technologies to allow learners to interact with complex scientific systems that cannot be experienced through normal everyday human experience. Using VR headsets in a world designed to depict electrostatic forces and fields, Dede and his colleagues found that learners could gain experiential intuition about concepts, which had once been extremely abstract. Learners felt immersed in a world of Maxwell's laws, an experience that most test students enjoyed and found more effective than traditional textbook learning.

Dede et al. state that effective instruction of science comes from cultivating students' ability to predict how various concepts will affect objects in the universe. John Belcher, an MIT physicist and faculty partner for this project, also believes that without a thorough intuitive comprehension of science concepts, quantitative formulas have little intrinsic meaning to a student. By interacting with the game or visualization, students will gradually develop an intuitive sense of how the virtual world works.

Dede also concluded that future iterations of VR technologies might benefit from embedding game-like structures in the experience, so that players are compelled to interact with these worlds. Their interviews with users suggested that today's learners are starting to expect game-like interactivity in their experience of virtual worlds. Gameplay in the virtual environment may motivate learners to explore the world and concepts further than they would otherwise.

SuperCharged! will provide scaffolding so that an inexperienced player can "jump right in" and begin interacting with the game world immediately. Early levels will be simple and straightforward, with clear objectives and paths for success. These levels will introduce a new EM concept, and ask players to interact with that concept for successful completion of the level. The virtual world will provide a significant amount of environmental feedback, such as field lines and multiple frames of references. Gradually, levels will include multiple concepts from previous levels, but at that point the player will be more comfortable with the environment and its unique rules. Finally, advanced levels will include multiple concepts and less environmental feedback, demanding a more challenging path for successful level completion.

Assessment of a student's understanding of the chosen material can be determined by analyzing their progress through the game. Rather than obstructing gameplay with straightforward quizzes, *SuperCharged!*'s level progression provides an excellent way to assess learning. Completion of a level will often indicate comprehension of the level's concept, and as a player advances through the game, it will demand even greater comprehension overall. In addition, the game will allow for background recording of each player's progress. By analyzing a data file with statistics such as level completion time and the number of gameplay errors, an instructor can determine how well a student understands the material. A student can focus solely on gameplay and level advancement, without the distraction of strict assessment. Without distracting the student from the gameplay, *SuperCharged!* can provide special assessment levels that are specifically designed to elicit performances where students might show their misconceptions in the game space, and track the mistakes to assess future improvement.

SuperCharged! will also include an editor that can be used by players to build their own levels. Using a click-and-drag style interface, players will be able to quickly and easily design complex levels which can be immediately played or traded with other players over the internet. By designing and building entertaining levels for *SuperCharged!*, a player proves not only their creativity, but also their mastery of the scientific content. While the editor is available to all players, those players who have the greatest understanding of Maxwell's laws will be able to devise the most playable and interesting levels. The learning theory of constructionism is the notion that people acquire new knowledge with effectively when they are engaged in constructing products that are personally meaningful to them. (Papert and Resnick resources here…) Thus, the very process of building a level from scratch will reinforce the learned concepts, as well as motivate the builder to play their own puzzle. In addition to the assessment generated by statistical tracking of the player's progress, *SuperCharged!* players and their instructors can also assess their learning by the creativity and playability of their level designs.