MIT GAMES-TO-TEACH PROJECT

Design Document for

CUCKOO TIME!

Mechanical Avian Polkas in Lederhosen

"What makes the cuckoo cuckoo?"™

Written by Philip Tan,
David Moisl, Zachary Nataf, Kurt Squire, & GTT team

Monday, May 27, 2002

VERSIONS

Version 1.0
Filled in Basic Stuff

Version 1.1
Kurt Squire. Integrated Zach’s document. Completed Assessments and misconceptions.

CUCKOO TIME!

It's 11:57, and do you know where your Cuckoo Bird is? Most people are unaware of this, but from the first minute to the 57^{th} minute of every hour, the cuckoo bird flies around the inside of the clock, passing time. Only moments before the hour, the gnomes who live in the clock, chase down the cuckoo bird, and return it to its perch. Why this last minute frantic chase to capture the Cuckoo Bird? Well, as you probably *do* know, gnomes are lazy little creatures would rather spend the hour napping and snacking on pretzels than tending their cuckoo bird.

Capturing the Cuckoo Bird can be tricky. Cuckoo Birds quickly dart to and fro, while the fat little gnomes struggle to move about the complex interworkings of the Cuckoo Clock. The sliest of gnomes learns to use the Cuckoo Clock to his advantage, manipulating pulleys, springs, levers, and pendullums to catch the Cuckoo Bird.

Cuckoo Time! is an action platform game where players chase a Cuckoo Bird about a Cuckoo Clock, manipulating simple machines to get the Cuckoo Bird. From a Newtonian Physics perspective, players are exploring the dynamics of working – playing with the transfer of Energy through Motion from the frenetic gnomes, in the case of *Cuckoo Time!*, to the parts of the clock.

The key to succeeding in *Cuckoo Time!* is making split-second decisions about which is the best path to get the Cuckoo Bird. For example, players are forced to quickly evaluate if they will have sufficient mass to lift another gnome up to a higher level using a lever / fulcrum contraption. *Cuckoo Time!* features both collaborative and competitive levels, as well as a fully functioning level editing tool so that players can design their own levels for the game.

GAMEPLAY

The *Cuckoo Time!* game is designed to give players an intuitive feel for the everyday workings of physics in the real world by letting them maneuver the gnomes through the tasks and undertakings within their fantasy world of the Cuckoo Clock. The Cuckoo Clock represents a kind of system or compound machine made up of a series of parts or very simple machines each representing one or two principles of Newtonian Mechanics. This documents describes the relationship between the clock parts or simple machines and their corresponding principle as made evident by the activities of the gnomes.

The gnomes who inhabit the clock represent the Energy in the system. Their work is to catch the cuckoo in order to return her to her perch. Using the clock parts as tools, force is produced when the gnomes activate the functioning of these simple machines to achieve their goal. Each simple machine also corresponds to a level of the game. Experiencing and understanding the function of the clock parts at each level is a means of access to the understanding of the physics principle that they embody. The seven basic machine types in the Cuckoo Clock can be identified as:

- The Lever
- The Inclined Plane
- The Wedge
- The Screw
- The Wheel and Axle
- The Pulley
- The Pendulum and Spring.

Each of the functioning parts or machines should have its individual or set of identifying sound effects. In the clock the seven machine types take the form of the following “clock parts” and other objects found in the clock:

- The Seesaw
- The Ramps, Stairs and Ladders
- The Pallets of the anchor escapement
- The Jackscrew elevator
- The Gears
- The Weights, Chains and Pulley
- The Pendulum and Spring.

The Corresponding Newtonian physics covered by the game include:

- Work, Energy, Force
- Kinematics, including Projectile Motion
- Newton’s Laws of Motion, including Friction and Centripetal Force
- Momentum and Collisions
- Circular Motion and Rotation

- Gravitation
- Oscillation

II. The Science of Work

In terms of Newtonian Mechanics the definition of Work is the transfer of Energy through Motion from the frenetic gnomes, in the case of *Cuckoo Time!*, to the parts of the clock. The gnomes are doing Work when they use Force on or through the clock parts as tools or machines to cause Motion. Motion is changing the position of an object a distance in the direction of the applied Force. Force is the pushing, pulling, turning, stretching, squeezing, bending, colliding and falling, that causes a change in the Motion or in the shape of an object, such as a clock part, the cuckoo or another gnome. The types of Forces that appear in the clock world include Gravity and Friction. Gravity is a universal Force. Every object in the universe exerts a Force on every other object, and that Force is Gravity. Friction is a Force that opposes Motion. It occurs when two surfaces rub against one another reducing the Motion of the objects, surfaces that sometimes come in the shape of slapstick gnomes.

Energy is the ability to do Work, that is, cause something to move or change. Machines cannot work without Energy. Due to Friction, the Work produced is usually less than the Energy used. According to the Law of Conservation of Energy, Energy may change from one form to another, but it cannot be created or destroyed. There are two types of Energy: Kinetic, the Energy of Motion and Potential or Stored Energy, the Energy of Position. Stored Energy is the Potential to cause change if certain conditions are met. The Potential of Gravity or Energy stored in a spring, for example which can be changed into Kinetic Energy with a push into movement.

The gnomes Kinetic Energy is transferred through Work into the Force that runs the machines, their actions set off the levers, the wheels and axils, the Jackscrew elevator, the gears, the weights, the springs and the pendulum.

III. The Clock-Works

First a brief description of what you would usually find in a cuckoo clock and how it works. Because these elements lend their functions to the possible activities of the gnome characters within the game and to the experience of physics principles that players will have access to.

The iron weights of a pendulum clock, usually in the shape of pinecones, is what powers the clock, in average over an eight-day period. For clocks with more than one weight, the first weight, along with the pendulum, provides the clock timekeeping function, the second weight controls the cuckoo and its movements, and in a clock with a music box or glockenspiel, a third weight controls the music.

The weights hang under the clock by chains which slowly drop as the clock operates. When the weights lower to the floor, the clock must be rewound. This is done by pulling down on the ring at the end of the chain, in order to raise the pinecone weights back up to the clock.

The weight represents potential Energy. It is an Energy storage device that depends on the earth's gravitational pull. The clock uses the stored Energy over the period of time it takes for the weight to fall. That Energy is governed by an escapement, the heart of a clock and essential to its timekeeping and reliability. The escapement with the pendulum precisely controls the release of the Energy stored in the tightened spring or lifted weight. As the escapement releases the stored Energy from the weights or spring, it turns a series of gears that control the hands on the clock, keeping the time.

The anchor escapement swings back and forth with the pendulum, its pallets alternately catching and releasing the escape wheel. The clock's movements are thus regulated by the natural period of the pendulum. The pendulums' swinging ensures that the pallet protrusions move the gear wheels tooth by tooth while the Motion of the pallet keep the pendulum moving. This recoil escapement allows for a long pendulum with a swing of one second.

The power of the mainspring travels through a multi-component gear train, the last component of which is the escape wheel. The escape wheel stops and starts intermittently as first one pallet stops the escape wheel, releases it, and then the other pallet stops it. The balance wheel moves the lever and its pallets to and fro at regular intervals. Thus, it is the balance that times the lever's movements and the lever that starts and stops the escape wheel.

Furthermore, pallets do much more than simply block and release the teeth of the escape wheel. On release, the pallet actually propels the balance wheel on its travel in the opposite direction. So the pallet is both a block and part of the anchor lever.

The interior world of the cuckoo clock in *Cuckoo Time!* does not represent the realistic space of a cuckoo clock. Inside a real cuckoo clock is a very cramped space. Besides the basic clock work with all its gears, escapement and pendulum parts are the wires to push out and tilt the bird, the lifters to work the bellows which force the air through the whistles sequentially to produce the "cuckoo" sound and a gong striker amongst other things. The clockworks in the *Cuckoo Time!* clock do not attempt to represent a functioning clock but abstracted elements with some unlikely but fun additions. For example, a clock with a pendulum would not usually have a mainspring as well.

IV. The Mass of a Cubic-Gnome and Physics Principles

Swinging from, climbing up, sliding (or rappelling) down chains and pendulums. Counterbalancing weights to ride up and down pulleys. Colliding with other gnomes to knock them off the Jackscrew elevator and platforms. Sliding down ramps and ladders. These are among some of the stunts and activities that the gnomes will get up to as they race around in the last three minutes of the hour trying to re-perch the cuckoo in time for her to call the new hour. What follows are the specific machines included in the game and how they relate to gameplay.

A. The Lever as Seesaw:

Kinematics, including Projectile Motion. Using the seesaw as a catapult (one gnome jumps from an intermediate platform onto one end of the seesaw representing a lever, which is a rigid bar balanced on a fulcrum (the fixed pivot point) the jumping gnome lands onto one end, the point of Effort Force which pushes down in the direction of the applied Force and lifts the opposite end, the Resistance Force or Load end on which another gnome is standing. The Load end lifts abruptly tossing the second gnome into space and catapults him onto a higher level platform.

B. The Inclined Plane

The Ramps, Stairs and Ladders. Ramps allow players to expend energy more slowly over time; whereas lifting a barrel up to a platform would demand a large, 1-shot expenditure of energy, using ramps allows the players to spread that energy consumption over time. Players can use ramps, stairs, and ladders to move up in eleveation – expending energy and gaining potential energy. Players need to gauge how long it will take to move, and if the energy savings is worth time trade-offs.

C. The Wedge

The Pallets of the anchor escapement. The wedge is the active version of the stationary inclined plane. This simple machine consists of a single or a pair of inclined planes set face-to-face that work with a Force in a direction perpendicular to that of the moving wedge. With adequate friction at the interfaces, the wedge becomes a separating, holding and stopping device. The metaphoric shape of the escapement is the anchor, which is a kind of wedge that helps to attach and hold the ship into the sand on the sea bottom. But the pallets, the protrusions at the ends of the anchor-shape appear more like rectangular blocks than wedges proper. The blocks could be revealed to actually be wedges in disguise

A gnome could knock a section of the pallet askew with his mallet (the percussive effect usually associated with driving wedges) but this action would show that the block is really made up of two wedges fitted together in the opposite direction of a double wedge to create a rectangle instead. Another gnome could knock it back so it spins back into place just in time for it to catch on the gear tooth of the escapement wheel between the “tick” and the “tock”.

D. The Screw

The Jackscrew elevator. The screw that is essentially a transfer device of Motion and/or Force is a modification of the wedge but designed to operate in a minimum space. In one sense, a screw is not as "simple" a machine as the others are because it depends on the lever to perform its operation. It can be looked at as a twisted wedge; it is a cylinder with an inclined plane wrapped around it. One way that the screw can function is to raise weights. In doing this it converts rotary Motion into straight line Motion. This is how the gnomes’ Jackscrew elevator will work.

E. The Wheel and Axle

The Gears. Gears are generally used for four reasons:

1: To reverse the direction of rotation

2. To increase or decrease the speed of rotation
3. To move rotational motion to a different axis
4. To keep the rotation of two axes synchronized

Thus, in *Cuckoo Time!* players can use gears to change directions or pick up velocity. Using levers, players will have the capability of turning on gear chains, or switching their direction. As the gnomes run over the gears, they gain a sense for how they affect the gnomes' motion. Further, in some levels, the gears will be connected to pulleys, forcing the gnomes to quickly analyze and predict if a gear ration will generate enough energy to lift a mass. Players will also encounter more complex gears, including worm gears, planetary gears, and chain belts. Players use gears to increase their kinetic energy. Kinetic energy is useful for jumping on pendulums.

F. The Pulley

The Weights, Chains and Pulley. Pulleys allow players to make distance / energy trade- offs. Players use pulleys to lift themselves, objects or other gnomes up to higher levels. Players can also use block and tackle rigs to pull other objects or other gnomes to the top.

G. The Pendulum and Spring

The Pendulum and Spring. Players

The gnomes can use the slinky-like coils of the spring to function as a slingshot or gnome cannon. Many students have alternative conceptions about pendulums that we hope to help them reconsider through *Cuckoo Time!* For instance, the period of the swing of a pendulum depends entirely on the distance between the pivot and the gnome hanging on the pendulum. The pendulum does not swing less over time (friction does not apply) and the velocity of the gnome as it grabs on the pendulum does not have any influence on the amplitude of its swing.

GAME OVERVIEW

Philosophy/Design Goals

High speed, highly silly action
Cuckoo Time! takes place entirely within the confines of a traditional German cuckoo clock. Unbeknownst to most, the insides of cuckoo clocks are filled with grumpy gnomes, polka music, beer, a goofy cuckoo, pratfalls, all with names derived from bad German puns. The spirit of the game should be lighthearted and tongue-in-cheek, emphasizing straightforward and frenetic gameplay.

One object/one principle approach
The inside of the cuckoo clock is full of clock parts and power-ups that help the gnomes catch the cuckoo and sabotage each other's attempts. Each of the clock parts obeys and demonstrates a single physical principle. For instance, a lever in the clock only operates on the principle of mechanical advantage; friction, mass and elasticity of the lever do not apply to gameplay strategies. When a player is considering the best way to use an object in the level, the appropriate physical principle should leap to mind. The use of clock parts or power-ups may influence either the player's gnome or its effects on other gnomes. Only cheat codes can change properties of the environment such as gravity.

Simple to learn, difficult to master
The game is very easy for a new player to pick up. Within a minute of a competitive multiplayer game, a new player should be able to make life difficult for experienced players. Solo and cooperative levels may take longer for new players to figure out, but a minute of play and exploration should give them some idea of how to solve the clock puzzles. To have complete mastery over the gamespace requires an instantaneous recognition of the properties and affordances of multiple mechanical objects. Such intuitions can only be developed through repeated gameplay.

Choices based on scientific thinking / strategy as a core gameplay mechanic
On each level, players will be force to choose between alternate paths in climbing to the top of the clock. For example, a player faces game situations where she might use a lever to pry open a door. The player must use her knowledge of simple machines to predict whether the machine will achieve the desired result. Other players might glance at the door and realize that they cannot generate enough energy to pry the door open. Thus, the player's knowledge of levers allows her to quickly analyze different strategies and choose the strategy that will be the most effective.

Level design as an integrated mode
A level editor will be featured prominently among the gameplay options and allow players to create their own levels as complex as the levels shipped with the game. Creating a playable level should require players to employ a large degree of creativity and a deep understanding of physics principles. Drastic adjustments to the physics of the

game that severely change gameplay, such as the loss of gravity, should only be available via cheat codes.

Common Questions

What is the game?
Cuckoo Time! is a multiplayer console video game with single player puzzle levels and a level editor. The game intends to answer the age-old question: How do gnomes manage to catch the cuckoo every hour? Everybody knows that when a cuckoo is not cuckooing, it flies freely inside its clock. How does it know when to come out? Little gnomes live inside cuckoo clocks, which is why most cuckoo clocks look like little houses. Every hour, they somehow manage to catch the cuckoo despite their short legs, amidst their habitual drinking, eating and sleeping. Obviously, their understanding of the clockworks and their strong arms allow them to catch the cuckoo so that they can place it on the little extending platform that pops out at the top of every hour.

Why create this game?
The inside of a clock is a bewildering place. However, laws of physics govern the behavior of all the complex machinery inside. The gnomes need to have a good understanding of those laws in order to move effectively within the clock. By tightly integrating gameplay setting, strategy and pedagogy, this game should provide a strong motivation for players to come to grips with fundamental concepts in AP-level Newtonian physics.

Where does a game level look like?
Players view the game space through an isometric camera, which allows clear line-of-sight to all parts of the 3D level. In each game level, there is a combination of gears, levers, switches, pendulums, stairs, elevators, pulleys, chains and other ‘clock parts’. The gnomes need to manipulate these parts in order to navigate from the bottom to the top of the clock, where the cuckoo flies between three different perches every twenty seconds. These clock parts are not fully mobile; a lever will not be able to detach from its fulcrum, although it would be free to pivot. Power-ups will fall from the top of the level to the ground at random intervals, allowing gnomes to gain a temporary advantage its opponents and its environment.

What do I control?
The player controls a single short, wooden, lederhosen-wearing, sausage-eating, beer-drinking, grumpy, German gnome. Because of their short legs, gnomes simply waddle and hop when on the ground. However, they have powerful arms that are effective at pulling, pushing and grabbing, giving them tremendous flexibility when tussling with each other or manipulating clock parts. They are also relatively fat, and thus, have considerable mass. Temporary power-ups will alter speed, jumping, mass and other properties and abilities of the gnomes.

What is the goal of the game?
Before the hour strikes, the player's gnome must get to the cuckoo, resting on the perches near the top of the cuckoo clock. If the gnome manages to touch the cuckoo, the player grabs on to its legs as the cuckoo flies towards the door at the top of the cuckoo clock. The cuckoo will then begin to call the hour and that player will win.

There are three different gameplay modes in the game: single-player, multiplayer competitive and multiplayer cooperative. Each mode features a different subset of power-ups based on their appropriateness to the gameplay. Each mode also ships with its own set of levels. Single-player levels are puzzles that have one specific solution and players need to grasp the laws of physics as represented by the game to solve the puzzles. Multiplayer competitive levels are similar but there will always be several different possible ways up the clock. A gnome on the ground level must be able to thwart a gnome on the way up via a combination of strategy, power-ups, knowledge of physics and aggressiveness. Multiplayer cooperative levels are the most complicated, as they will require two or more gnomes to perform tasks in tandem and in time to catch the cuckoo.

All levels have a time limit, although the single-player and cooperative modes have longer playing times than the competitive mode. A typical competitive game round has a time limit of two minutes. If time runs out in a competitive level, the game switches to "Hatching Time!", a sudden-death stage. Multiple hatches open on the sides of the clock and gnomes now attempt to bump each other out of the clock. A rain of power-ups accompanies the beginning of Hatching Time! and the last gnome standing in the clock wins the game. The cuckoo flies continuously during Hatching Time! and gnomes will not be able to catch it. Cooperative and single-player levels end when the time limit expires and players will have the option of retrying the level.

What is different about *Cuckoo Time!*?
Many games currently available in the market have a very poor representation of physics. In their defense, realistic physics in games often make games less playable or fun. *Cuckoo Time!*'s approach is to employ an abstraction of physics in its gameplay where each object in the game behaves in a simplified manner that clearly illustrates a single principle of physics. By limiting the complexity of the simulation to 'ideal' conditions, this game hopes to address the root of common, basic misconceptions of physics. Because the clock parts behave according to highly predictable, repeatable laws, a rapid and intuitive understanding of those laws will be come a crucial component of devising gameplay strategies and winning tactics.

Who is the target audience? How will they learn through playing the game?
The behavior of the clock parts and the physics of the gnomes can be understood either as a simplified version of real physical laws or as predictable gameplay mechanics. Game players from ages 8 to 28 tend to assimilate predictable gameplay mechanics quickly and easily, especially when those mechanics determine victory or failure in a game. Further reinforcement from in-game tutorials, accompanying documentation and classroom syllabi will help players connect their understanding of the mechanics to actual laws of physics. This transfer of knowledge will probably not occur until players encounter the

same material in their schoolwork. Therefore, the target audience for the game (8 to 28) is considerably larger compared to the target audience for the educational content within the game (12 to 18).

What will people learn through playing this game?
Students will develop intuitive understandings of the laws of Newtonian Mechanics. In particular, students learn:

- Work energy and power
- Newton's Laws
- Simple and Complex Machines

The clock parts and the movements of the gnomes are all based on physical principles outlined by the first half of the Physics C syllabus of the Advanced Placement Program, which addresses Newtonian Mechanics. More information can be found below in the "Parts of the Clock" and "AP Physics Content" sections. Players will learn about Physics concepts by interacting with the clock parts, such as frictionless and weightless pulleys. From these abstracted but easily understood behaviors, players will have an incentive to absorb basic physical principles as fundamental components of gameplay that they can use to formulate winning strategies.

Describe the Controls
Standard joypad / keyboard controls control the movement of the gnome. There is an action button and a jump button. Pressing the action button will allow the gnome to interact with any object at any point in time.

USER SCENARIOS

User Scenario 1

Jim, a 16-year-old, sees *Cuckoo Time!* running on an Xbox at his local electronics store. Intrigued by the opening animation, which features a brief, comic glimpse of the life of a gnome in a clock, he presses the Start button on the controller to sample the game. The game menu that appears allows him to choose between the different game modes, the level editor or change various gameplay settings. Jim selects ‘Single player’ by scrolling through the list of options using the analog joystick and pressing the ‘A’ button.

The menu scrolls down, off the screen. The background, which shows the insides of a clock filled with stationary pendulums, zooms and fills the screen. Low-key polka music begins to play. The text ‘Choose a level’ drops down from the top, the number ‘1’ flanked by two horizontal arrows slides in from the side, and a description of the first level jumps up below the number. The description reads “Swing Low, Sweet Cuckoo; Grab pendulums and climb to the top!” Believing this to be a good place to start, Jim presses ‘A’ and the text jumps away from the screen.

The polka music suddenly increases in speed and volume. A cuckoo flies in to the scene and perches near the top of the level. The background rotates to an isometric view, rotating around the Y-axis several times and zooming into a gnome scampering in at the bottom of the level, barking with a gruff, exaggerated German accent “Ach! Zwei minuten und ve schtill haff nacht kaut der Cuckoo! Schwing on der pendulums to katch it! Schnell!” The numbers “2:00” zips in from the right in front of the background, shrinking to the upper-left corner. The camera zooms out to reveal the entire level as the gnome says, “Start!” The timer in the upper-left corner begins to count down.

Jim has no idea what to do but he begins to fiddle with the analog stick. As he does so, the gnome waddles in the direction indicated by the joystick. Suddenly, the gnome says “Press A to jump and grab!” Jim does so and the gnome jumps a little. Jim notices that the gnome jumps well horizontally but does not jump very high. He also notices that no matter how he places the gnome, the gnome cannot jump high enough to reach the lowest pendulum.

He notices a short stairway that ends in front of one of the pendulums, and makes the gnome waddle up the stairway. As the gnome reaches the end of the stairway, Jim presses the ‘A’ button and the gnome jumps off, grabbing on the pendulum. The pendulum begins to swing slowly. As soon as the pendulum approaches another, Jim presses ‘A’ again, and the gnome jumps to the next pendulum. However, the gnome fails to catch the pendulum as it passes below it. Jim realizes that he needs to wait for the pendulum to swing to its maximum height before jumping to the next or the gnome will not have sufficient altitude to catch the next one.

The gnome falls to the ground with a very grumpy thud, and Jim makes his way to the stairway again. This time, he notices something fall from the sky: a mug of beer. As his gnome moves over it, it stops, grabs the beer and chugs it with a satisfying burp. Jim then notices that his gnome is moving faster. At the top of the stairway, Jim presses 'A' again, and the gnome begins to swing on the first pendulum. At the very highest point of the swing, Jim presses 'A' and the gnome successfully jumps and grabs on to the next pendulum.

Jim looks at the top of the screen and notices that he has one-and-a-half minutes left. He also notices that all the pendulums are suspended from the roof of the clock, and that each pendulum will allow him to gain a little height and reach the next. The pendulums are not all pointing the same direction but whenever the gnome grabs onto one, it begins swinging towards the next appropriate pendulum.

Jim continues jumping from pendulum to pendulum, thinking that this is not so difficult. Suddenly, the gnome drops to the ground again and Jim realizes that he made the gnome jump too early again. However, he had been maintaining the same tempo of swinging-then-jumping all the time. Why did the gnome fall?

As he contemplates this, he notices that there is a pair of Lederhosen on the floor of the level; it must have fallen to the ground earlier when he was paying attention to the pendulums. As the gnome waddles over it (the effects of the beer have worn off by now) the gnome pulls on the traditional German garment and gives a hearty yell. Jim does not notice anything else different until he makes the gnome jump off the stairway again. The gnome makes a jump two times higher and further than it did before! Jim wonders if this means that he does not have to wait for the pendulum to swing to its highest height before jumping. As he attempts to verify this, the gnome falls short of the second pendulum and hits the ground. Clearly, the extra height in jumping did not change his horizontal jump distance.

Only one minute left, the music is becoming more frantic. The gnome jumps on the first pendulum, then the second, then the third. Jim realizes now why he missed the higher pendulums earlier; the pendulums are swinging faster as he gets higher! He thus needs to adjust his timing as he progresses higher among the pendulums. When he reaches the last one in the level, he realizes that one more jump will fling him headlong into the cuckoo. The pendulum is swinging so fast, though, that it is difficult for him to judge exactly when to let go.

Fortunately, Jim presses 'A' at the right time, and the gnome grabs the cuckoo with ten seconds to spare! The camera zooms into the gnome and shows it hanging on to the legs of the cuckoo as the cuckoo attempts to take off. The gnome effectively hang-glides into a door on the side of the clock as the camera tracks back to reveal the exterior of the clock. The music abruptly ends as the clock chimes, with the cuckoo punctuating every chime with its trademark call. As it ends, a hatch opens on the front of the clock and the camera zooms into it, revealing the gnome giving a thumbs-up and a mischievous smirk.

Jim feels good, having completed the first level of a game he had not heard of three minutes ago. During this level, he had received several important lessons in vector motion (horizontal versus vertical jump heights) and periodic pendulum motion (the increasing speed of the pendulums) that would be reinforced through further play.

User Scenario 2

A 10-year-old boy, Tim, walks up to Jim and asks if they could play a competitive multiplayer game. Tim has been playing this game at home and is now eager to trounce Jim and show off his gaming expertise. Jim, on the other hand, is fairly confident he can beat this squirt at his own game, having played through 7 levels of *Cuckoo Time!* on his first try. Jim quits his single-player game, returns to the opening menu, and selects 'Competitive Multiplayer'.

The game asks all players to press 'A' on their controllers. Tim and Jim do so, and as they do, two differently colored gnomes appear on the screen, one sleeping and one eating. As Jim moves his analog stick to the side, the color of the clothing of his gnome changes, and he picks a bright red color to identify his gnome. Tim settles on a yellow ensemble and verbally taunts Jim as both of them press 'A' to confirm their choices.

The clock level fills the screen, rotating around the Y-axis and striking up upbeat polka music. Both of the gnomes run in from the sides of the screen as the cuckoo flies in and perches near the top of the level. The timer begins at 2 minutes, and both gnomes yell "Start!"

Jim notices that the power-ups are falling a lot faster in this mode, and there are a few power-ups that he had not seen before. He grabs the first two beers he sees, running circles around Tim and finding a big lever-operated spool that runs a chain around a high pulley. The chain terminates with a weight and Jim realizes that if he lowers the chain, he will be able to climb up to the cuckoo perches.

Learning from the single-player levels, Jim moves his gnome to the outermost edge of the lever and presses 'B', the action button. Jim's gnome grabs the lever and as Jim guides it using his joystick, the gnome pulls the lever around its axis, lowering the chain at a rapid rate.

Tim, on the other hand, is preparing a different route up the clock. A series of gears connect to one big gear that stretches from the ground all the way to the top of the clock. The gears connect to a counterweight dangling on a chain that Tim needs to retrieve to get the gears moving. Having played this level before, Tim realizes he needs to get a Knockwurst or Currywurst power-up first, so he directs his attention towards sabotaging Jim's effort.

Jim succeeds in bringing the chain down to its lowest height. If he had a Lederhosen power-up, he could just jump and grab it. Unfortunately, he does not, so he needs to climb a stairway and jump onto the chain. The effects of the beer wearing off, Jim takes a while to reach the top of the stairway. As he prepares to jump, Tim begins pulling the lever-spool in the opposite direction, raising the chain! Jim's gnome jumps and misses the rising chain, falling on the ground with a hard thump.

One minute to go, and a Currywurst falls from the sky. Both Jim and Tim intend to grab it; Jim needs it for the extra jump height and Tim needs it for the extra mass. Jim's gnome first runs to grab another beer, giving him a speed boost. As he heads for the Currywurst, though, Jim realizes that his gnome cannot corner very well, resulting in the gnome missing and running past the sausage entirely. Too late, he realizes that the third swig of beer in a game causes a loss of control over the turning of his gnome! Tim takes advantage of Jim's mistake and grabs the Currywurst, turning his gnome very fat indeed.

Tim begins to jump up a stairway that brings him closer to the counterweight. Jim, not about to be outdone, takes advantage of his extra speed to catch up to Tim on the stairway with every intention to ram him off the stairs. Unfortunately, Jim's gnome is less massive than Tim's in its fattened state, so when they collide, Jim himself bounces off the stairs while Tim hardly budges an inch.

Tim manages to catch the counterweight, pulling it down and setting the giant gear in motion. Jim sees the opportunity and jumps onto the gear with Tim closely behind. Jim attempts to jump further up the gear while Tim's curry-powered boost gives him an advantage. The cuckoo waits for the two of them at the top of the gear, and just as Tim is about to reach the perches…

************ HATCHING TIME! ********

The timer hits zero and the cuckoo takes off from its perch, flying continuously around the clock. Hatches open all over the level, especially near the bottom. Both Tim and Jim jump off the giant gear, looking for the power-ups as five fall at once. Jim goes for the Knockwurst to make him harder to push off, while Tim grabs the fiddle as his own gnome returns back to normal size. The polka is now insanely fast as Tim manages to swing the fiddle at Jim, knocking him on his fat bottom. This leaves him vulnerable to subsequent attacks as Tim expertly beats Jim into a hatch and out of the clock, leaving Tim as the sole surviving gnome!

The camera zooms in on Tim's gnome, grinning smugly, then cranes downwards to reveal a very dazed red-attired gnome on the floor below the clock with little cuckoos flying around its head.

User Scenario 3

Despite the thrashing he received at the electronics store, Jim had so much fun with *Cuckoo Time!* that he bought it to play at home. He plays through the single-player levels with his 12-year-old sister, Kim, watching from the couch. Kim recognizes that some of the behaviors of the clock parts match what she was learning in her grade school science classes, especially for the levers. She asks Jim if she could try playing the game. Jim, reluctant to stop playing the addictive game, decides to try out cooperative multiplayer mode instead so that both of them can play at the same time.

Like competitive multiplayer mode, both Kim and Jim get to select the color of the clothes worn by their respective gnomes. This time, however, the game allows Kim and Jim to select the level they wish to play, similar to the single-player mode. Jim notices that the levels are much, much larger and more than in the other two modes. However, the timer gives them three minutes to solve the puzzle instead of two.

The game begins, along with the polka music. Jim notices a ledge that leads up to a series of gears, which he is confident of being able to manipulate. However, getting up to the ledge is tricky, as neither chains nor stairways lead to it. Kim notices a seesaw lever near the ledge, and there happens to be a stairway on the other side of the seesaw. The fulcrum of the seesaw is not right in the center; the longer part of the seesaw is touching the ground and near the ledge, the shorter end is elevated and is near the stairway.

Jim walks to the long edge of the seesaw and asks Kim to try jumping off the stairway, onto the short end of the seesaw. Kim does so but the seesaw does not budge. While Kim's gnome waits on the elevated end of the seesaw, Jim's gnome walks towards Kim. The level tilts until the long end is the same height as the ledge. However, as Jim walks towards the ledge, the seesaw tips back to normal. Clearly, there is no real mechanical advantage in this arrangement; either Kim's gnome would need to gain mass or Jim's gnome would have to run fast and lose weight.

Thankfully, a Knockwurst power-up is on the ground, so Kim picks it up and her gnome becomes very fat. Slowly, she makes her way to the top of the stairway and jumps. Her jump is half the normal distance but she still reaches the seesaw, tipping it skyward and flinging Jim onto the ledge. After thanking Kim, Jim realizes the gears have a counterweight system similar to the competitive level that he played with Tim. Quickly, his gnome jumps at the loose chain and pulls the counterweight up, starting the gears ticking. Jim, back on the ground, gets himself on the seesaw as Kim tries her best to guide her overweight gnome to the top of the stairway. Again, she jumps and Jim races across the ledge to get a handhold on the gears.

All this negotiation and puzzling took two minutes and Jim is realizing the time limit is fast approaching. However, just as he reaches the top by hopping from one moving gear to another, the cuckoo leaves its perch and heads to another perch! Jim looks on with dismay as he tries to figure out how the alternate routes may work.

Meanwhile, Kim has been actively collecting power-ups on the ground, having great fun with some of the goofier effects. As the timer counts down to 10 seconds, an accordion falls from the sky and she walks over it. Her gnome immediately picks it up and begins playing the silliest polka riff ever, startling the cuckoo and making it move back to the top of the gears! Jim, who has had his gnome on the top of the gears all this time, instantly contacts the cuckoo. The ending hang-gliding animation begins, with the music ending and both Kim and Jim's gnomes giving thumbs-up signs from the hatches.

CLOCK PARTS AND POWER-UPS

Clock Parts

The Cuckoo Clock parts are designed to provide barriers and conduits for accessing spaces where the Cuckoo Bird might be hiding. The Cuckoo Clocks will have the following parts.

- Extension Springs
- Compression Springs
- Coil Springs
- See-saw Levers
- Threaded Levers
- Lever Elevators
- Pendulums
- Gears
  - Worm gears
  - Planetary gears.
- Escapement
- Chains
- Counterweights
- Pulleys
- Block-and-Tackle
- Block-and-Tackle Elevator

Power-Ups

Power-ups are important for balancing out the game by introducing a random, silly element into the largely deterministic gameplay. If a power-up is crucial for using certain clock parts correctly, they will appear more frequently during the levels that need them. Other power-ups may also appear, of course. Power-ups enter a level by falling from the roof of the cuckoo clock and gnomes use power-ups by walking over them.

- **Knockwurst (Sausage)**
  This heavy treat fills a gnome up instantly, thus slowing him down and practically negating the gnome's ability to jump. The effect lasts for a short period. The added mass might be useful when dealing with clock parts that require additional mass to operate properly or when colliding against another gnome.

- **Currywurst (Spicy Sausage)**
  The same as Knockwurst but the spices give the gnome an additional 'gas-powered' jump boost, increasing the height of the gnome's jump for a short period.

- **Bock (Beer)**
  One swig and gnomes are able to run faster and cut corners sharper. Any more taken while under effect of last beer increases speed further but controls get progressively looser.

- **Lederhosen**
  The mass of a gnome decreases, allowing for higher and further jumps for a short period.

- **Sauerkraut**
  The gnome's spinach! The arms of the gnome balloon and become very powerful, allowing for more powerful swings from chains and pendulums or faster operation of clock parts. The arms are so heavy, though, that the gnome cannot jump while the effects of the sauerkraut are active.

- **Pocket Watch**
  An extremely rare power-up that adds thirty seconds to the timer.

- **Stollen (Fruitcake)**
  A 'land-mine' that halves the speed of a gnome while keeping the actual mass of the gnome unchanged.

Multiplayer Power-ups

The following power-ups are only available in the two multiplayer modes.

- **Glühvein**
  A potent wine that intoxicates all the gnomes at once! Every gnome reacts as if each had drunk one Bock.

- **Käsekuchen (Cheesecake)**
  A greasy dessert that causes all gnomes in the level to lose their ability to grip and renders the action button useless for 10 seconds. Gnomes hanging onto pendulums or chains immediately fall to the floor when any gnome eats a Käsekuchen.

- **German Chocolate Cake**
  A rich dessert that slows all the gnomes at one! Every gnome reacts as if each had eaten one Stollen.

- **Spieldose (Music Box)**
  Playing this mesmerizing trinket will cause any gnome in its radius to be entranced for a short period while the gnome that activated the music box is immune to its effects.

- **Shepherd's Cane**
  If the powered-up gnome touches another gnome, the latter must follow the former around for a short period. A very useful tool when combined with the following two power-ups.

- **Birkenstuks**
  The bearer kicks another gnome across the length of the level until it reaches a wall. They are useful for combat and for reaching areas across wide gaps.

- **Tuba**
  The powered-up gnome is slow but can flings another gnome skyward. They are useful for combat and for reaching tall ledges but not the cuckoo.

- **Accordion**
  This fearful instrument will scare the cuckoo from its current resting place.

Hatching Time! Power-ups
The following power-ups are only available during Hatching Time!

- **Pretzel**
  Because traditional German pretzels resemble crossed arms in prayer, gnomes that eat pretzels become invincible to the following power-ups and will wear a bright halo for a short period.

- **Lebkuchen (Gingerbread cookies)**
  Gnomes that eat these tasty treats become invincible to a single attack from the following power-ups and will wear a bright halo until they receive an attack.

- **Fiddle**
  The gnome that picks this up begins playing a fiddle solo and uses the violin to swat other gnomes across a short distance.

- **Ow-di car logo**
  The gnome flings four ninja throwing stars in all directions. If the stars hit another gnome, the gnome is stunned for a short period and is vulnerable to attack.

- **Bonkswagon car logo**
  This is similar to the Ow-di car logo but there is only one projectile. It can ricochet three times against the sides of the clock.

- **Mersheardes car logo**
  This is similar to the Bonkswagon car logo but it moves slowly and can change direction in mid-air, depending on the heading of the controlling gnome.

LEVEL EDITING

Overview

The most powerful learning opportunities may come from player-designed levels. In designing effective levels, players need to carefully construct levers, pulleys, and powerups so that getting to the top of the clock will be challenging, but not impossible. There are two primary variables that need to be considered in the design of the level editor: object placement and object type / size.

Variable Object Types

Players will not have full control over the size of levers, springs, etc. Rather, they can choose from a set of pre-existing parts. This will simplify the construction process, and allow mechanical advantage to be "black - boxed" as opposed to computed for the design of every part. A component design tool could be packaged with the game, or made available to players after release, much as *Sims* design tools are downloadable *from The Sims* website.

The player begins by laying down platforms. The player can also choose from any one of 75 pre-existing platform placements that ship with the game. We expect that novice game designers will choose a setting that looks interesting, and then gradually move on to setting up their own platforms.

The design screen will show a toolbox of tool parts. When a player clicks on a part, a dialog box pops up. Players can then choose the exact dimensions of the part that they want via pull down menus (Each part has a set of pull down menus corresponding to the particular variables for that part, e.g. spring constant, mass, volume, dimensions).

Object Placement

Players place the objects in the environment, which is arranged in a 3D grid. Objects "snap" to the grid so as to avoid problems lining up parts. Lego Alpha Team employs a similar technique.

Multiple Camera Angles

At any time, players can freely manipulate the camera, or move the camera among pre-set camera points, which are set every 45 degrees in overhead positions (much like the camera in *Lego Alpha*, *The Sims*, or *SimCity 2000*. Multiple camera angles is necessary for

AP PHYSICS CONTENT

The Physics C Course

This course ordinarily forms the first part of the college sequence that serves as the foundation in physics for students majoring in the physical sciences or engineering. The sequence is parallel to or preceded by mathematics courses that include calculus. Methods of calculus are used wherever appropriate in formulating physical principles and in applying them to physical problems. The sequence is more intensive and analytic than that in the B course. Strong emphasis is placed on solving a variety of challenging problems, some requiring calculus. The subject matter of the C course is principally mechanics, and electricity and magnetism, with approximately equal emphasis on these two areas. The C course is the first part of a sequence which in college is sometimes a very intensive one-year course but often extends over one and one-half to two years, with a laboratory component.

In the typical C course, roughly one-half year is devoted to mechanics. Use of calculus in problem solving and in derivations is expected to increase as the course progresses. In the second half-year of the C course, the primary emphasis is on classical electricity and magnetism. Calculus is used freely in formulating principles and in solving problems.

Most colleges and universities include additional topics such as wave motion, thermal physics, optics, alternating current circuits, or special relativity in a C course. Although wave motion, optics, and thermal physics are usually the most commonly included, there is little uniformity among such offerings, and these topics are not included in the Physics C examination. The Development Committee recommends that supplementary material be added to a Physics C course when possible. Many teachers have found that a good time to do this is late in the year, after the AP Exams have been given.

Newtonian Mechanics Content

Cuckoo Time! addresses topics in the first half of the Physics C course, namely, Newtonian Mechanics. The following list outlines this portion of the AP syllabus:

- Kinematics (including vectors, vector algebra, components of vectors, coordinate systems, displacement, velocity, and acceleration)
    - Motion in one dimension
    - Motion in two dimensions including projectile motion
- Newton's laws of motion (including friction and centripetal force)
    - Static equilibrium (first law)
    - Dynamics of a single particle (second law)
    - Systems of two or more bodies (third law)

C. Work, energy, power
- Work and work-energy theorem
- Conservative forces and potential energy

- Conservation of energy
- Power

D. Systems of particles, linear momentum
- Center of mass
- Impulse and momentum
- Conservation of linear momentum, collisions

E. Circular motion and rotation
- Uniform circular motion
- Angular momentum and its conservation
- Point particles
- Extended bodies including rotational inertia
- Torque and rotational statics
- Rotational kinematics and dynamics

F. Oscillations and gravitation
- Simple harmonic motion (dynamics and energy relationships)
- Mass on a spring
- Pendulum and other oscillations
- Newton's law of gravity
- Orbits of planets and satellites
  - Circular
  - General

Textbooks

The following textbooks are commonly used in colleges and typify the level of the C course. However, the inclusion of a text does not constitute endorsement by the College Board, ETS, or the AP Physics Development Committee.

- Crummett, William P. and Arthur B. Western, *University Physics: Models and Applications*, 1st ed. New York: WCB/McGraw Hill, 1994.
- Fishbane, Paul M., Stephen Gasiorowicz, and Stephen T. Thornton, *Physics for Scientists and Engineers*, 2nd ed. Upper Saddle River, N.J.: Prentice Hall, 1996.
- Halliday, David, Robert Resnick, and Jearl Walker, *Fundamentals of Physics*, 5th ed. New York: John Wiley, 1997.
- Halliday, David, Robert Resnick, and Kenneth Krane, *Physics, Parts I and II*, 4th ed. New York: John Wiley, 1992.
- Serway, R. A., *Physics: For Scientists and Engineers*, 5th ed. Fort Worth: Saunders, 1999.
- Serway, R.A., *Principles of Physics*, 2nd ed. Fort Worth: Saunders, 1998.
- Sanny, Jeff and William Moebs, *University Physics*, 1st ed. New York: WCB/McGraw Hill 1996.
- Tipler, Paul A., *Physics for Scientists and Engineers*, 4th ed. New York: Freeman/Worth, 1999.

- Wolfson, Richard, and Jay M. Pasachoff, *Physics for Scientists and Engineers*, 3rd ed. Reading, Mass.: Addison Wesley Longman, 1999.
- Young, Hugh D. and Roger A. Freedman, *University Physics*, 9th ed. Reading, Mass.: Addison Wesley Longman, 1996.

Web information on AP Physics

More information is available at http://www.collegeboard.com/ap/students/physics/index.html

PEDAGOGICAL APPROACHES

Overview

Perhaps no subject is as bereft with student misconceptions as physics. Even though many students pass successfully complete Physics courses, most graduate from Physics courses with little intuitive understandings of the most basic physics concepts, such as how forces operate or how machines work.

Cuckoo Time! tries to support learning of Physics through "play." Learning through play is a much talked-about, but under theorized area. However, embedded within most notions of learning through play is the notion that learning through play allows learners to observe phenomena, build and test hypothesis, build artifacts that are representations of their understandings, and engage in fantastical situations. Underlying these notions are several pedagogical approaches of interest to science educators including the design of resources to combat misconceptions, simulating phenomena in 4 dimensions, digital manipulatives to create intuitive understandings of Physics phenomena, collaborative learning approaches, and robust assessment mechanisms.

Combating Misconceptions

The content covered in *Cuckoo Time!* may seem intuitive or simplistic to some. Certainly, fundamental physics concepts and simple machines are introduced to students at an early age. However, science educators have shown that even when students graduate from physics courses, they frequently fail to develop understandings of even simple phenomena. Wolff-Michael Roth, for example, has studied students' understandings of levers for over a decade (1991). Roth finds that most students reason through lever problems through trial and error, thinking through a series of decision trees rather than developing grounded understandings of the quantitative relationships embodied in physical phenomena. Rarely do even "successful" students develop systematic conceptions of how physical phenomena operate. In *Cuckoo Time!*, the levels are designed to elicit students' misconceptions. For example, mass increasing power-ups are placed next to pendulums to lure players into thinking that increased mass will . For a full list of student misconceptions related to Machines, see Appendix A.

Simulating Phenomena in 4D

Cuckoo Time! takes advantage of computers' ability to simulate phenomena. While the attributes of simple machines like levers, pulleys, gears, springs, or pendulums certainly can be demonstrated offline, computer games allow players to manipulate these machines in order to achieve aims. Players can interact with representations that are static in textbooks, or fixed in laboratories. Players can experiment with these machines, seeing how different variables interact, such as differing masses on a pendulum (Most high school graduates believe that the period of pendulums is governed by the weight at the end of the pendulum. Of course, all of this experimentation take place within the world of the video game, where an intuitive understanding of physical phenomena has real functional value.

Intuitive Understandings of Physics

Cuckoo Time! is designed to produce powerful intuitive understandings of Physics concepts in gamers by leveraging their ability to quickly ascertain how interactive environments operate. In other words, any platform gamers (indeed, most any American) under the age of 25 can tell you that in Super Mario Brothers, Mushrooms double your size, stars make you invincible, fire flowers let you shoot fire balls. Player develop powerful intuitions for how objects in the world interact. Players know how to time jumps, the precise point to land on turtles to send them ricocheting off into the distance, or how to judge the periods of oscillating platforms. In other words, whereas gamers typically develop intuitive understandings of how interactive gaming environments are governed, *Cuckoo Time!* allows them to develop intuitive understandings of machines and physical phenomena.

Collaborative Learning

Cuckoo Time! includes several collaborative levels, where players must work together to catch the Cuckoo. Players must work together in developing and negotiating strategies. For example, two players might identify three possible paths for getting to the top, via swinging and climbing on pendulums, using levers as springboards, or using gears to accelerate their movement, which then might give them sufficient energy to push a lever. By articulating, advocating, defending, and debating strategies, players are forced to reflect on their actions, and develop strategies that can be transferred to new situations.

Learning By Design

Ultimately, the most interesting pedagogical opportunities in *Cuckoo Time!* may come from giving players the opportunity to design and play their own levels. Through designing levels, players must consider the dynamics of a level design: What is really the work output of a lever? How much mass would be needed to propel a gnome 1 story in the air? As such, the level design component of *Cuckoo Time!* employs constructionist (Papert, 1984 Resnick 1996) techniques. Players develop deeper understandings of the rules governing physical phenomena by constructing artifacts that embody their understandings.

One can easily imagine a unit where instructors have players present their level designs, and explain why they included particular design features – a design document, if you will. Through this documentation and presentation of ideas, players are able to refine and articulate their ideas, which is known to promote transfer into new contexts.

Assessment Opportunities

Cuckoo Time! can be used for multiple assessment strategies. Players can assess their own learning through success in the game; the game provides instant and constant feedback on students' understandings in the world. Second players can get feedback from other players in both the collaborative and competitive mode. Gamers frequently share and debate strategies in collaborative modes. Further, debriefing and discussing strategy is common in competitive games.

Cuckoo Time! also includes mechanisms designed to support more formalized assessments of learning. *Cuckoo Time!* captures data that can be used to assess students' learning. *Cuckoo Time!* captures:

- The time spent per puzzle
- Percent puzzles completed and missed.

Thus, teachers can examine the puzzles to quickly see which ones give students the most troubles. Further, teachers can construct puzzles that can serve as assessments, or give design challenges as assessments.

RESOURCES

http://modeling.asu.edu/modeling-HS.html

APPENDIX A: MISCONCEPTIONS IN PHYSICS

Forces and Motion

1. The only "natural" motion is for an object to be at rest.
2. If an object is at rest, no forces are acting on the object.
3. A rigid solid cannot be compressed or stretched.
4. Only animate objects can exert a force. Thus, if an object is at rest on a table, no forces are acting upon it.
5. Force is a property of an object. An object has force and when it runs out of force it stops moving.
6. The motion of an object is always in the direction of the net force applied to the object.
7. Large objects exert a greater force than small objects.
8. A force is needed to keep an object moving with a constant speed.
9. Friction always hinders motion. Thus, you always want to eliminate friction.
10. Frictional forces are due to irregularities in surfaces moving past each other.
11. Rocket propulsion is due to exhaust gases pushing on something behind the rocket.
12. Time is defined in terms of its measurement.
13. The location of an object can be described by stating its distance from a given point (ignoring direction).
14. The terms distance and displacement are synonymous and may be used interchangeably. Thus the distance an object travels and its displacement are always the same.
15. Velocity is another word for speed. An object's speed and velocity are always the same.
16. Acceleration is confused with speed.
17. Acceleration always means that an object is speeding up.
18. Acceleration is always in a straight line.
19. Acceleration always occurs in the same direction as an object is moving.
20. If an object has a speed of zero (even instantaneously), it has no acceleration.

Forces and Fluids

1. Failing to be able to identify the direction in which a force is acting.
2. Believing that any force times any distance is work.
3. Believing that machines put out more work than we put in.

4. Not realizing that machines simply change the form of the work we do (i.e. trade off force for distance or distance for force).

Harmonic Motion

1. The period of oscillation depends on the amplitude.
2. The restoring force is constant at all points in the oscillation.
3. The heavier a pendulum bob, the shorter its period.
4. All pendulum motion is perfect simple harmonic motion, for any initial angle.
5. Harmonic oscillators go forever.
6. A pendulum accelerates through lowest point of its swing.
7. Amplitude of oscillations is measured peak-to-peak.
8. The acceleration is zero at the end points of the motion of a pendulum.