

WALLCOLOGY: DESIGN OF A SIMULATION ENGINE FOR LEARNERS' EMBODIED INQUIRY
IN POPULATION ECOLOGY

BY

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THESIS

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SUMMARY

WallCology is a population ecology simulation built on the Embedded Phenomena framework (Moher, 2006). This thesis will discuss the motivation for implementing WallCology. Then discuss the two iterations of WallCology as well as two studies conducted using WallCology. It will follow this with a detailed look at the implementation of the second iteration of WallCology. The thesis ends with WallCology's contributions, conclusions drawn from the two studies, WallCology's limitations and possible future work.

1. INTRODUCTION

WallCology is a population ecology simulation built on the Embedded Phenomena framework (Moher, 2006). The primary motivation for the creation of WallCology is to bring an engaging and authentic means of studying ecology in the classroom with technologies that are readily available in most classrooms. WallCology, currently in its third iteration, has been tested in three different classrooms. Student and teacher feedback from these studies have helped to continuously modify and expand the simulation.

Population ecology, because of its largely observational nature, can be difficult to teach in a typical classroom setting. Ecology study in the classroom usually involves textbooks, worksheets, maybe a classroom pet, and perhaps a trip to the zoo. These usual methods may be augmented with the use of modeling applications such as NetLogo to highlight mathematical principles in population ecology. While each of these are informative and can be engaging, they lack the experience of how ecologists conduct science in the field. WallCology aims to help bring this experience into the classroom by creating an environment within which students can take on the role of ecologists and learn while engaging in activities that, at least at the basic level, approximate those used by ecologists in the field. Students are given a partial view of a larger virtual ecosystem using computers as portals. These portals, called WallScopes, allow students to view the environment, as well as the inhabitants of the ecosystem. The inhabitants of the virtual ecosystem are imagined “creatures” with observable characteristics such as morphology and behavior. The second implementation also simulated creature life cycles and predator/prey relationships between creatures. WallScopes also act as points of interaction between the real world and the virtual ecosystem. In the first version of WallCology, the portals were in fixed locations, but could be moved around in the second version, thus giving students the ability to choose where to place the WallScopes.

WallCology is similar to other Embedded Phenomena in that there is a central server that serves various clients and also makes use of the physical aspects of the classroom by closely mapping classroom walls to the walls that make up the virtual ecosystem. This mapping can also take into

consideration local information such as a classroom wall's proximity to a window or air-conditioning unit to define the virtual environment. It differs from previous Embedded Phenomena in that it is an agent-based rather than event-driven simulation. Creating an agent-based simulation requires that the server maintain information for each creature that exists within the virtual world. This requirement creates a problem common to many simulations: computational and memory costs. Storing creature information is relatively straightforward and can be accomplished using a simple database (WallCology utilizes a MySQL database). Updating creature information, however, is more complex because the server must continuously update the positions and status of hundreds, or even thousands, of creatures at any given time. WallCology overcomes this issue by distributing some of the server's computational costs to the clients (WallScopes).

WallCology also extends the Embedded Phenomena framework by adding a few interactive features that did not exist in previous phenomena. Though RoomBugs (Barron, 2006), an existing Embedded Phenomenon, allowed for indirect interactions with the system, most Embedded Phenomena (Moher, 2006) have been purely observational. WallCology provides affordances for direct interaction with, and manipulation of, the simulation state. The nature of the interactions provided by WallCology is similar to that of embodied interactions found in ubiquitous computing, in which actions in the real world translate to the virtual world almost directly. For example, observers can scare creatures by making too much noise near a WallScope. Using this method of interaction allows students to conduct embodied investigation, where an individual can more closely play the role of a scientist by executing tasks in a similar manner to practicing scientists. WallCology also allows distributed phenomenon, where two different classrooms can observe and interact with the same phenomenon regardless of their physical locations. However these interactions are only possible at the edges of the physical world (the walls), thus virtually adjoining distant physical spaces.

The partial view afforded by a WallScope presents challenges similar to the ones ecologists face in the real world. These challenges are especially evident during population estimation where questions of sampling and estimation become exceedingly complex. Scientists trying to predict the number of lions in

a given jungle do not have the resources to count each and every lion in the jungle nor do they have access to the whole jungle. Scientists must also be mindful of the impact of their observations on the animals that they are observing. Interactions available through the WallScopes, though limited, help highlight the negative effects of poor observation practices and the benefits of proper data collection.

There have been two studies conducted using WallCology. The first study was conducted in a 7th grade classroom, and focused on population estimation and species differentiation (Uphoff, 2007). A comparison between the pre and post tests showed that the students' understanding of population estimation increased. Student interviews revealed that features of the simulation, such as creature reactions to noise, aided students in accepting the simulation as "real". This ability to accept the simulation as a reality also seemed to help motivate the students to conduct their research. Classroom experience showed that the WallScopes failed to effectively deliver the environmental attributes (temperature and humidity) to the students. The data gathered in the pilot study was used to make updates to WallCology. The subsequent study, conducted in a pair of 4th grade classrooms, addressed a different set of learning goals: population estimation, population dynamics, life cycle, predation, and classification. The data gathered in this study through field-guides and interviews showed an increase in the students' knowledge of predation as well as a slight increase in their understanding of population dynamics. The in class experience also revealed that the students did not notice the subtle reactions to noise, unlike the 7th graders in the previous study. The 4th graders recorded and used the environmental characteristics more frequently than the 7th graders.

2. COMPUTER AUGMENTED LEARNING ENVIRONMENTS

2.1. Overview

Computers are very pervasive and have become commonplace classroom tools (Kleiner, 2002). However, they are primarily used by students and teachers for email, word processing, preparation, creating presentations, taking notes, or online research (Russell, 2003, Becker, 2001). Past applications have sought to extend the utility of computers by using them (1) to create embodied virtual environments that support science inquiry and (2) to model or simulate population ecology. *Hunting of the Snark* (Rogers, 2002) integrated a wide variety of technologies created an environment where students interacted with an imaginary creature using real objects. *Ambient Wood* (Rogers, 2002) and *Ambient Horn* (Randell, 2004) introduced technology into a woodland area and augmented the real world with virtual cues and clues, creating an information rich learning environment. (Klopfer, 2002) allowed students to play the role of environmental detectives in the real world using information gathered from a virtual world through PDAs. *Savannah* (Benford, 2004) used technology to enable students to play the role of lions in a virtual Savannah. *StarLogo* (Resnick, 1996) and *NetLogo* (Wilensky, 2004) on the other hand use technologies to model complex phenomena by presenting the phenomena as parallel decentralized interactions between virtual agents.

2.2. Embodied Inquiry in Virtual Environments

2.2.1. Hunting of the Snark

Using ambient, or unseen (Weiser, 1994), technologies, (Rogers, 2002) implemented a mixed reality adventure game called *The Hunting of the Snark*. In this application, pairs of students interacted with multiple tangible and ubiquitous technologies to discover characteristics of a mythical creature, the Snark, which was never directly visualized. These discoveries and interactions occurred in a mixed reality environment and required that the students make use of both the physical space as well as the technologies afforded to them. For example to discover clues students used an RFID-enabled PDA as a

'clue locator'. When the PDA approached a clue the PDA made a sound and displayed a picture of the clue. Using this picture, the student could then locate the nearby physical object that represented the clue. Another example of interaction with the Snark was to put RFID-tagged plastic food into a 'feeding area' equipped with an RFID reader. The response of the Snark to this interaction would indicate to the student whether or not the Snark liked or disliked the food. Hunting of the Snark proved to be a very engaging activity (Rogers, 2002). The researchers also found that the interactions with the virtual world are more successful when they represented familiar and intuitive interactions in the real world (Rogers, 2002).

2.2.2. Ambient Wood & Ambient Horn

In Ambient Wood (Rogers, 2002), a woodland area was augmented using various technologies to provide a more informative view of the woodland. The extra information was provided through three modes: displays installed as "periscopes", wireless speakers, and PDAs. The periscopes, displays mounted on a pole, displayed multiple movies that could be selected and then watched one at a time by the students. The wireless speakers played sounds to attract attention to certain processes in the physical environment that were "impossible to see with the naked eye" (Rogers, 2002). For example the life cycle of a creature. The sound is followed by an image displayed on the PDA with a voice over that gave the students information about the inconspicuous occurrences. Students could also actively collect data using light and moisture measurement tools connected to the PDAs.

The overall experience in Ambient Wood was comprised of three stages. In the first stage, pairs of students explored the woodland discovering various characteristics of the area using the modes mentioned above. After the discovery stage the pairs entered a 'den' where information was consolidated and reflected upon. To aid this process there was an interactive whiteboard and a large computer display. Before leaving the den the pair is asked to hypothesize about the environment under different conditions (namely a different season) and the effects of introducing species into the ecosystem. In the final stage, students returned to the woodland to perform experiments. The objective of the hypotheses stage was to

hypothesize the outcome of a change in the environment or adding different species to the wooded area of the woodland using the data gathered in the first stage. The experiments were conducted by placing RFID tagged “artifacts”, that represented two different species, either together or one at a time close to a RFID reader located by the periscope. This action represented the introduction of the species into the woodland. Once the students placed these artifacts the periscope would display the outcome. After this, the students predicted and tested (using the PDAs that represented moisture probes) what would happen if the clearing area of the woodland became really wet or really dry. The PDA readings reflected the scenario being tested showing either very wet (when in low grounds) and very dry (when in high grounds). Audio cues also made students aware of the effects of the wet or dry condition in a given area.

Ambient Wood provided “highly engaging and novel learning experiences” (Rogers, 2002). Ambient Wood also showed that uncommon technology creates a high level of interest and intrigue in children and thus motivates them to explore on their own.

Ambient Wood was less successful in delivering the audio cues through wireless speakers because they were easily missed or tuned out by the students amidst all of the other sounds occurring naturally (Rogers, 2002). Ambient Horn (Randell, 2004) was designed to address the issue of perceptive vs. ambient noise raised by Ambient Wood. The experience of Ambient Horn is very similar to that of Ambient Wood, except that Ambient Horn uses only one mode by which to provide the extra information in the woodland area. Mobile ‘horns’ carried around by the children as well as wireless speakers (as in Ambient Wood) presented audible cues (representing various organisms and processes) to the students. The cues could be triggered by the student entering an area or explicitly pressing a button on the mobile horn. This way the cues remained surprising but at the same time allowed for students to attend to them when suitable. Using this dual means of delivering the cues enhanced the learning activity since important cues were not missed while at the same time they did not interrupt the students (Randell, 2004).

2.2.3. Savannah

Savannah (Benford, 2004) is a location based game that challenges students to take on the role of lions. Equipped with portable GPS systems, students explored, marked their territory, hunted for food, and protected their cubs in a virtual Savannah overlaid on an open soccer field. Students (lions) carried out their missions on the field where they could track their locations using the GPS systems and communicated with the game server using a PDA and a Wi-Fi network. Between missions, students returned to the 'den', a part of the classroom, for planning and reflecting using a shared interactive interface.

The field was split up into different regions where the lions encountered various animals, some prey and others threats. The players used PDAs to explore the virtual jungle using three senses: sight, sound, and smell. The PDAs also allowed players to carry out basic tasks such as attack, which caused a change in their status. For example the attack action caused the player to lose energy.

Using these affordances the students carried out two missions: marking territory and hunting. In the first mission the students explored the field in a short time (approximately 10 minutes) and marked every new sight, sound or smell they encountered by pressing a button on the PDA. Students then returned to the den and plotted as much of the savannah as they could remember. In the second mission the students reentered the savannah and attempted to find food. The foods that were available required a certain amount of lions "attacking" together to successfully kill. Some of the foods available could not actually be killed by any number of lions and could even lead to one of the lions being killed. Another consideration that the students had to account for here is the amount of food obtained from a kill. More lions attacking a prey made the kill easier but also made the share smaller for each individual lion.

2.2.4. Environmental Detectives

(Klopfer, 2002) presented Environmental Detectives, a handheld based augmented reality simulation, "simulations that bridge the virtual and real worlds" (Klopfer, 2002), used to explore the implications of moving simulations from desktops to handhelds and "develop and examine a new

simulation platform that is designed from the ground up for handheld to create augmented reality simulations” (Klopfer, 2002). There are five advantages of handhelds described by (Klopfer, 2002)

- *“portability –can take the computer to different sites and move around within a site*
- *social interactivity – can exchange data and collaborate with other people face to face*
- *context sensitivity– can gather data unique to the current location, environment, and time, including both real and simulated data*
- *connectivity – can connect handhelds to data collection devices, other handhelds, and to a common network that creates a true shared environment*
- *individuality – can provide unique scaffolding that is customized to the individual’s path of investigation.”*

The aim of the author is to harness these advantages in the new simulation platform. As a proof of concept, Environmental Detectives is an envisioned simulation based on the platform where students use PDAs to collect data about a river near a town where many illnesses have occurred. The data is presented in various ways from virtual readings of the environment to interviews with the local townspeople. The students also have to take digital pictures when possible to support their findings and could even have to track down individuals who “sneak out the backdoor”.

2.2.5. Embedded Phenomena

Embedded Phenomena (Moher, 2006) is a framework with the following four features:

- *“Simulated scientific phenomena are “mapped” onto the physical space of the classroom.*
- *The state of the simulation is represented through distributed media located around the classroom representing “portals” into that phenomenon depicting local state information corresponding to that mapping.*
- *The simulations are persistent, running and being presented continuously over extended time periods, concurrent with the regular instructional flow.*
- *Students monitor and manipulate of the state of the simulation through those media, collectively gathering evidence to solve a problem or answer a question.”*

Embedded Phenomena framework utilizes a server and client architecture to run the various phenomena. The server side is written in Java and is accessible using the internet. Another important restriction, while not a part of the framework, is that the simulations should run on classroom computers

without the need of any extra hardware. This restriction is the motivation for using Adobe Flash and HTML web pages for all client side applications.

There have been three phenomena based on the Embedded Phenomena framework (other than WallCology). HelioRoom embeds the solar system within the confines of a classroom. RoomQuake maps an active fault line rich in seismic activity onto the floor of a classroom. RoomBugs (discussed in greater detail in the next section) transforms a classroom into a farming community teeming with various species of “bugs”.

HelioRoom is a planetary phenomenon that displays the orbits of planets in the solar system. Four Tablet PCs, representing windows into the planetary orbits, are mounted (one per wall) around the classroom. Colored discs whiz by each screen one after the other varying only in color, speed and optical depth. Students observe these discs to determine their correspondence with the actual planets. The evidence observable through the portals is limited to the speed of the discs and occlusions. The speeds of the discs are relative to the actual orbital speeds of the planets but can be sped up or slowed down by any given magnitude. Also the speed here refers to radial speed not linear, so they are the speeds of the planets as perceived from the Sun.

RoomQuake is a seismic phenomenon based on the premise that the floor of the classroom is the location of an active fault line. At least three Tablet PCs are placed flat on desks around the classroom. The PCs represent seismographs that when read together help students locate the magnitude and location of earthquakes that occur in the classroom. Students can then use the series of earthquakes to map out the fault line. To add to the experience, a loud subwoofer is hooked up to a PC and rumbles (rather loudly) to simulate the sound of an earthquake.

2.3. Ecology Modeling & Simulating

2.3.1. StarLogo & NetLogo

There are many modeling applications that help illustrate the mathematics involved in various science domains, including population dynamics. StarLogo (Resnick, 1996) is a programming language based on the Logo programming language that can model complex phenomena. "In traditional versions of Logo, students create pictures and animations by giving commands to a graphic 'turtle.'" (Resnick, 1996) To allow for even more complex models, StarLogo expands Logo in three main ways: (1) it allows for far more turtles than Logo, (2) it gives the turtles more "senses" and (3) it "reifies the turtles' world" (Resnick, 1996). The world in StarLogo is divided into "patches" that are logically equivalent to immobile turtles and can have all of the same complex programmer defined properties. These updates allow for decentralized (without central authority) models that occur from simple agent-to-agent and agent-to-world interactions. Such models occur in phenomena ranging from ecology to economics. For example the user can program the turtles to behave like ants foraging for food with a few simple rules that determine their response to interactions with each other and their environment. When hundreds of these run in parallel, a pattern may emerge even though the ants are not being controlled by the queen ant but rather simple behavioral rules for interacting with each other and the surroundings. StarLogo was originally implemented specifically for a super computer but has since been ported to Java, whereby it can be executed on many different platforms.

"NetLogo is the next generation of the series of multi-agent modeling languages including StarLogo" (Wilensky, 2004). NetLogo is also a development platform allowing for users to quickly develop a new model and a graphic user interface for that model. NetLogo is implemented in Java and has a large and wide user base (Wilensky, 2004). As it is the next generation, it is faster and more advanced than StarLogo. The graphics have been updated to involve not only many different shapes and sizes of turtles but even 3D turtles. NetLogo comes bundled with numerous pre-built models that allow users to explore before creating their own. NetLogo also gives real-time graphs of the model allowing users to see

emerging patterns more easily. NetLogo also gives the user the ability to interact with the turtles directly via the cursor. One of the pre-programmed models call “bug hunt speed” illustrates the evolution that occurs in prey due to predators. The user acts as a predator hunting bugs that move with varying speed. The user can more easily catch (click on with the cursor) the slower bugs and so as the model runs the slower bugs begin to disappear leaving mostly the faster bugs.

2.3.2. RoomBugs

Room Bugs (Barron, 2006) is a population ecology simulation built on the Embedded Phenomena framework that maps a virtual farming community, infested with insects, onto the classroom. The students monitor and control the population of the insects to attract desirable species while repelling harmful species.

To monitor insect populations students use a virtual “sandtrap.” The sandtrap is displayed on a tablet computer that does not show students the insects themselves, but rather insect tracks (unique to each species) that are dynamically created by the simulation to reflect current populations. The students were provided a printed field guide, containing information about each type of “bug”, to aid in identifying the different species. So to estimate the population of species A in a given area, the students can count the number of tracks (that correspond to species A) found in a sandbox in that area and then generalize, by multiplying that number by the total area.

To control the insect population, students used pesticides and humidity. However, students could not directly introduce changes, but were required to fill out “Environmental Action Forms,” manipulations that were implemented overnight. The results of their manipulations were reflected the following day in the insect tracks found on the sandtraps, and reinforced through a mock newspaper that gave clues to the effects of their manipulations within the context of local stories.

A pilot study conducted using RoomBugs found that students showed improvement in their perceptions on their ability to play the role of scientists (Barron, 2006). This was evidenced by comparing

the pre and post Tests of Science Related Attitudes (TOSRA) (Fraser, 1978) that showed an 18% decrease in agreement with the statement, “it is better to be told scientific facts than to find them out from experiments” and an increase in agreement of 13% in the statement, “I would rather find out why something happens by doing an experiment than being told” (Barron, 2006). However the results also showed that there was a slight gap in causal understanding due to the indirectness of the interactions, such as having to fill out action forms rather than performing the actions (Barron, 2006).

2.3.3. WallCology

WallCology is an ecology simulation aimed at many of the same goals as the applications mentioned above. Like RoomBugs, WallCology helps students understand some of the principles of population ecology such as environmental preference. WallCology also attempts to model real life phenomena, namely population dynamics, using agents that make decisions based on their surroundings and other agents just like StarLogo and NetLogo. However due to strict curriculum guide lines and complexity, WallCology is not fully decentralized. Some of the control is given to a population driver that restricts species populations from dipping too low or rising too high. Also, WallCology is more visual than RoomBugs, StarLogo and NetLogo that represent the animals abstractly using footprints and icons respectively. WallCology uses animations that are rendered using 3D software giving the animals a more realistic appearance.

WallCology creates a virtual environment for embodies inquiry using pretty modest technologies and could be easily run on most classroom PCs without installing any new software. Students play the role of ecologists researching a newly found ecosystem inside of their classroom walls. WallCology also enables distant classrooms to share a classroom wall and collaborate during their research. WallCology is well into its third version and will continue to grow as a simulation and an education tool allowing students to explore and affect the virtual world within their walls.

3. WALLCOLOGY 1.0

3.1 Design and Experience

This chapter outlines the initial implementation of the WallCology simulation environment, including a discussion of the learning goals of the instructional unit, the application affordances designed to support those learning goals, and the experiences of a seventh grade classroom which used WallCology as part of a unit on population ecology.

3.2. Learning Goals and Design Elements

The initial implementation of WallCology was designed to give students experience in two authentic scientific practices: the categorization of collections of living creatures into disjoint species, and the estimation of the sizes of mobile populations from samples. Neither is as simple as might appear at first glance. Biologists encountering previously unseen creatures face the challenge of categorizing those creatures into domain, kingdom, phylum, class, order, family, genus, species and subspecies based on the morphology of the creatures (i.e., their appearance), behavior, and habitat preferences of the creatures. Morphology alone is often insufficient; variation in appearance within species is common especially during various life stages, for example the striking difference between caterpillars and butterflies, while at the same time distinct species may share similar morphological features, for example False Cobras which mimic the Indian Cobra. Estimating populations of mobile creatures from samples raises such problematic issues as where and when to sample, how to account for creatures that enter or leave the sampling area during the counting process, and the size of the sampling area relative to the territory housing the larger population.

3.2.1. Species Differentiation

The instructional goal of the former problem, which will be called the *species identification* problem, was not to have learners identify creatures as belonging to pre-determined species, but instead to problematize the process of categorization itself; the objective was to prompt discussion and

argumentation within the class. If the creatures fell into disjoint, easily recognized types, the activity would be unlikely to raise that discussion. The design strategy adopted was to introduce four kinds of creatures within the environment. Two of the creature types shared a similar appearance, but behaved in different ways. The other two creatures were more visually distinct from each other, but demonstrated similar behavior.

While graphic model differences were sufficient to problematize morphology, the introduction of behavioral characteristics was more challenging. Habitat preferences were assigned to each of the creature types, with some “preferring” warmer or colder, or wetter or drier, areas. Different WallScopes were then configured to reflect variation in temperature and humidity, as reflected in persistent displays within the WallScope, and the simulation programmed in such a way as to reflect creature habitat preferences¹. The creatures also showed differential preferences with respect walking along the metal pipes or wall surfaces. (Table 1) outlines the different creature types as well as their characteristics.

Behavioral differences were reflected in two ways, through locomotive differences and in their reaction to the presence of human beings. The locomotive patterns of the creatures differed in both velocity and saccades, with some creatures displaying relatively smooth motion and others more jittery, start-and-stop patterns. Reaction to human presence was realized by monitoring the ambient sound level using built-in microphones on the WallScopes; when the level surpassed pre-defined thresholds, some creatures would scatter off screen, some would “freeze” in place, and others would continue their normal locomotive patterns, reflecting a variety of behavioral responses found in nature.

¹ Habitat preferences were probabilistic rather than absolute. Creatures preferring colder climates, for example, were much more likely to appear in those areas, but appeared in smaller numbers even in warmer areas. It was felt that an absolute dichotomy would preclude the desired discussion.

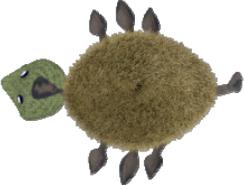
	Morphology	Movement	Habitat Preference	Population Size
A		Noisy: become translucent and slow as to blend in with the environment.	Cold. Pipes only.	Large
B		Normal: jittery back and forth.	Hot. Pipes only.	Large
C		Noisy: Dart, move very quickly across screen. Normal: linear, no jitter.	Humid (wet). Pipes only.	Medium
D		Noisy: same as quiet. Normal: non-linear, no jitter.	Arid (dry). Wall only.	Small

Table 1: Creatures A and B though similar in movement prefer different temperatures and have different morphology. Creatures C and D though similar in morphology vastly differ in habitats and behavior.

3.2.2. Population Estimation

The instruction goal of the *population estimation* problem was to introduce learners to two specific techniques used by population ecologists, and to give them an opportunity to practice in the use of these techniques.

The simpler of the two techniques is static sampling. Here, an “instantaneous” sample is taken from a defined geographic region of known size (i.e., the area of the WallScope); the estimate of the population size within an entire wall is obtained by multiplying the sample counts of the different creatures by the ratio of the wall area to the WallScope area. A second technique, a simplified version of the capture-recapture method (Pollock, 2000), employs a “tagging” strategy; on initial sampling, creatures are

marked to indicate their presence in the initial sample, and on a subsequent “resample,” the ratio of marked to unmarked creatures can be used to obtain a more accurate sample estimate².

While the methods appear relatively straightforward, the mobility of the creatures complicates the task for the students. In WallCology 1.0, the velocity of creature locomotion was set sufficiently high to ensure that creatures would be moving into and out of the WallScope frame fairly rapidly; frustrating attempts to obtain an “instantaneous” count of the multiple creatures, and, intentionally, no “snapshot” capability was provided within the user interface. It was expected that students would have to invent, negotiate, and implement counting strategies of their own in order to obtain the sample counts.

3.3. Classroom Experience

A pilot study conducted with WallCology 1.0 took place in a 7th grade classroom in an urban middle school. A lesson plan was constructed with the help of the teacher. The study lasted nearly eight weeks with the first four weeks focused on species differentiation and the final four weeks focused on population estimation. The overarching goal for the students was to build a “field guide”. The students took pre/post tests and answered questions during one-on-one follow up interviews. TOSRA tests were also given with the pre/post tests. Additional data was also collected using cameras that recorded the class during WallCology related instruction.

3.3.1. WallCology Setup and Process

The set up for the pilot study used five Tablet PC’s mounted in various locations, such as by the teacher’s desk or under a wall mounted television. The class was split up into five groups with about five to six students per group. Each group was assigned to a WallScope, thus limiting any one group’s view. WallCology related instruction was given to the students almost every other day. A typical day with WallCology instruction involved a brief lecture on science content and goals for the day. Then the

² This method assumes the following equation to hold true $C/N = R/M$ where C is the number of animals captured the second time, N is the total population, R is the number of animals recaptured and M is the number of animals initially captured. The simple reorganization yields the equation $N = (C*M)/R$.

students were given time to make observations, collect data, and interact with the WallScopes. Following this the students held a discussion led by the teacher and researchers where collaboration and hypothesizing took place.

During the first four weeks students were tasked with identifying the species. Identification meant that the students had to distinguish one species from another using morphology, behavior, and habitat as points of argument. Extensive observations were made by each group and then noted in the group's field guide. There was a theoretical *right* species classification, but the goal of the exercise was more about making reasonable claims and providing evidence since in the field it is impossible to give a definite answer without blood tests (which we did not allow). The final four weeks students collected data on the population of each species. They first used static sampling to get acquainted with counting on the WallScopes. After this they were briefed on the capture/recapture method and then finally, over a span of two days, they conducted capture and recapture.

3.3.2. Results

The pre and post tests consisted of two sections, one testing the students on species differentiation and the other population estimation. The students did very well on the species differentiation section both in the pre and post tests. Students used morphology, behavior and environment as evidence to support their answers to the questions in this section. In the population estimation section the students increased their knowledge of the process of the capture/recapture method but did not show that the students understood the formula. In the post interviews, many students stated that they were easily able to believe that the creatures really were inside of their walls, many went on to state that this ability to *believe* in the simulation increased their motivation in conducting the science work (which was, at times, boring). Almost every student stated that they really enjoyed the tagging activity. A careful study of the field guides showed that the students did not closely observe the humidity/temperature readings unless when specifically told to do so. This may have been the result of constantly displaying the readings on the WallScopes without calling attention to them. The TOSRA pre

and post tests showed that the students increased their self-efficacy assessment as shown by an increased agreement $t(21) = 2.17, p < .05$ with the statement, "I would rather do my own experiments instead of finding something out from a teacher." Also by the increased disagreement $t(21) = 2.10, p < .05$ and $t(21) = 3.04, p < .01$ with the statements, "Doing experiments is not as good as finding out information from teachers" and "Repeating experiments to check my results is a waste of time." Group discussions during class also revealed that the students had an increased interest in ecology and would enjoy repeating the experiments to confirm or revise their hypotheses.

4. WALLCOLOGY 2.0

4.1 Design and Experience

This chapter outlines the second implementation of the WallCology simulation environment by discussing the modified learning goals of the instructional unit, the additional application affordances needed to support the new learning goals, and the experiences of a pair of 4th grade classrooms which used WallCology as part of their unit on ecology.

4.2. Modified Learning Goals and Supporting Affordances

The second implementation of WallCology was designed to give students experience in five authentic scientific practices: discovering patterns in dynamic populations using multiple samples, the classification of species using life cycles, habitat attribution, determining predator-prey relationships, and collaborating with peers. Each of these practices poses interesting challenges for the students to overcome. A dynamic population raises many issues, for example, how often must the population be re-estimated, is there a pattern within a population, how does the population of one creature affect another's, and what is causing the change in population? The introduction of creature life cycles meant that along with morphological, behavioral and habitat differences between species, one must take into account the differences within a species at different life stages. For example tadpoles never leave the water nor do they have legs, in fact they are morphologically closer to fish than frogs. Habitat preferences themselves raise an interesting question; why do certain animals prefer certain climates. Answering this question can be less than straight forward especially because creatures wander outside of their preferred habitat for various reasons like escaping predators; sea turtles often leave the sea to lay eggs on land. Predator-prey relationships are not always easy to determine because predators are not constantly feasting on prey and often the act itself can occur out of sight or very quickly, for example a frog eating a fly.

4.2.1. Dynamic Populations

Motivation to implement dynamic populations partly arose from the addition of life cycles to the simulation, which required that creatures die and give birth. Dynamic populations also helped illustrate and provide evidence for the population relationship between predators and prey. Students could now observe how a change in the population of one affected the other. WallCology uses a model that resembles the Lotka-Volterra equations in which the population of a predator follows, in time, the population of its prey. Prey in turn responded inversely to the population of its predators. (Figure 1) shows an example of this pattern.

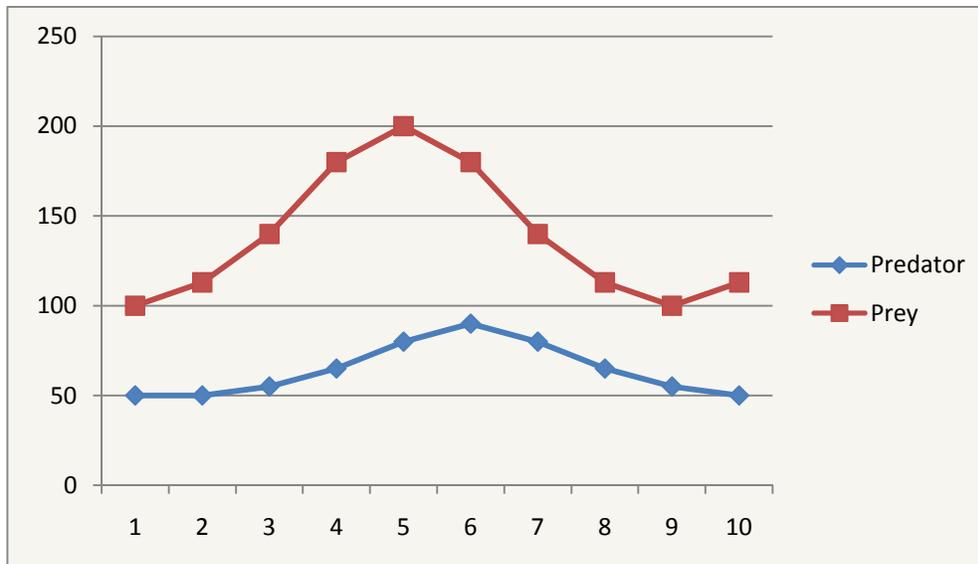


Figure 1: An example of predator and prey populations, as implemented in WallCology.

4.2.2. Life Cycles

The instructional goal of creature life cycles was (a) to introduce the concept of life stages, (b) to show how creatures can take vastly different shapes at different life stages and (c) to add complexity to species identification. The two former goals (a and b) are manifested mainly through the use of different graphic models per type of creature depending on its life stage. The last goal is presented through an added activity of *species classification* as opposed to only species differentiation. Life stages provide evidence, albeit limited, as to the class of an animal (fish, amphibian, reptile, bird, mammal and insect).

As with species differentiation this activity was problematized by carefully designing the life stages of each of the creatures. Two of the creatures gave external birth (laid eggs) and the third creature gave live birth (only mammals give live birth). One of the egg laying creatures was also holometabolous with four distinct life stages: egg, larva, pupa and adult (only certain insects go through these life stages). Students could use these key pieces of observable evidence to conclusively classify the insect and mammal creatures. The other egg laying creature could reasonably be classified as amphibian, reptile or bird. This uncertainty was purposeful so as to prompt discussions about the existence of peculiar creatures like penguins (birds that do not fly). The graphic models also provided extra pieces of evidence to further argue the classifications such as fur (for the mammal creature), six legs (for the insect creature) and an apparent hard shell (for the reptile creature). The graphic models for each creature are provided in (Table 2), these creatures purposefully resemble real life creatures to allow students to cite as well as ponder knowledge obtained about actual animals (beetle, turtle and skunk).

4.2.3. Fit: Habitat and Morphology

While modeling the creatures for WallCology 2.0, creature fit was taken into account, such that creatures would appear in line with their environmental preferences. The mammalian creature is warm blooded and lives in cold temperatures, therefore it was given fur. The reptilian creature preferred warmer temperatures and so its exterior appeared scaly. The insect creature had no environmental preferences.

4.2.4. Predator-Prey Relationships

The goal of this activity was to give a basis for discussion about predator and prey relationships in general. To conclusively discover the predator-prey relationship students have to observe the creatures closely and catch a predator in action. This action is shown very abstractly in WallCology by having the prey simply disappear when the predator's mouth moves over the prey. The relationships were purposefully made to be reasonable to allow students even without direct observation to hypothesize as to the possible predators and prey. For example, the mammal creature only eats reptile eggs as opposed to the child or adult reptile because of the

Class	Life Stages	Habitat	Noise Reaction	Prey
Insect	Egg  Larva  Pupa  Adult 	Egg pipe. Larvae pipe. Pupa wall. Indifferent.	Scurry.	None
Reptile	Egg  Child  Adult 	Wall. Hot.	None.	Insect
Mammal	Child  Adult 	Wall. Cold.	None.	Reptile Insect

Table 2: Shows the properties of the creatures used in the second iteration of WallCology. Note that the creatures had no humidity preferences.

shell. Another consideration that was taken into account when deciding the predator-prey relationships was the notion of prey defense. The insect creature lays its eggs on the pipes to avoid having them eaten by the other creatures. Also, the insect creature in its adult stage moves much quicker therefore becoming too quick for the mammal creature to catch and eat. All of these subtle characteristics were built into the simulation to allow rich discussions when deciding the predator-prey relationships.

4.2.5. Collaboration

Collaboration is an essential part of scientific practice. Science labs are not created for individuals but rather groups of scientists working together towards a common goal. Science also relies on collaboration to convey, test and retest findings. For this reason WallCology 2.0 attempts to promote learner collaboration within and between classrooms by providing limited views and a shared phenomenon. Students within a classroom must collaborate with other students in the classroom because any one WallScope will only provide a limited view of the phenomenon. The same can be applied to two classes observing and affecting the same set of creatures, which are free to wander between the two classes.

4.3. Classroom Experience

This section will discuss a study conducted with WallCology 2.0 took place in a pair of 4th grade classrooms, in an urban school. Two classrooms, with different set ups, were used for three reasons: to conduct a shared phenomenon, to test the effects of portable WallScopes, and to test the effectiveness of mobile instruments. The setup and process of WallCology 2.0 will be discussed as well as the lesson plan. The study lasted five weeks with the goal that each student would have a finished field guide by the end. Individual pre and post interviews were used to gather information on students' prior and summative understandings. Logs on the status of the simulation were taken every thirty seconds during the five weeks. A camera in each class recorded class discussions and followed the activities of a randomly selected group of students. This section will end with a discussion of the results of the intervention.

4.3.1. WallCology Setup, Process

One of the classes utilized four 24-inch iMacs (one per wall) as their WallScopes. The iMacs could not be moved, however the two iPod Touches which representing mobile instruments, could be (Figure 2). These instruments could be used to get either the temperature or humidity reading, using the respective iPod, for any of the four WallScopes in that classroom. The WallScopes did not display the

temperature or humidity readings for his class, forcing them to use the mobile instruments to get these readings. Student groups (five in all) rotated between the WallScopes.



Figure 2: Mobile instrument thermometer.

The second class's WallScopes were *portable* Tablet PCs. Each Tablet PC was augmented with USB iButton readers that allowed students to move the WallScope between twelve iButtons™ glued to the walls in clusters of three (Figure 3). Each group was assigned one of the four clusters. The temperature and humidity readings for this group were ever present on their WallScopes as with previous iteration of WallCology.

Both classes were given the same field guides (one per student). The goals for both classes were also the same; fill out the field guide. The two classrooms shared (both physically and virtually) one wall, allowing the creatures to travel between classrooms. As with the pilot study, a typical day of WallCology activity began with a discussion of the topic as well as the goals for the day. After this discussion, the students were allowed to go to the WallScopes and make observations to further complete their field guides.



Figure 3: Portable WallScope.

4.3.2. Lesson Plan, Field Guide and Activities

The educational portion of WallCology 2.0 was created with extensive collaboration with the two 4th grade teachers. This collaboration led to the development of the learning goals, a lesson plan, a field guide, and the activities supported by WallCology 2.0. The former two contributed a great deal to the design and implementation of the latter.

The learning goals and the lesson plan were almost entirely designed by the teachers with the technical limitations of WallCology 2.0 in mind. The learning goals supported were based on the learning standards for the school and the state. A lesson plan that would match these learning goals was created by modifying the teachers' pre-existing lesson plan. To achieve this, numerous meetings with the teachers were scheduled before and throughout the development of WallCology 2.0.

The field guide, which was a direct result of the collaboration with the teachers, consisted of three creature pages (one per species), a page for species classification, and a page for population estimation. The creature pages provided students with pictures of the various life stages for the given species because the teachers wanted to simplify the task of species classification. To fill out the creature pages students had to fill in the name, morphology, habitat and behavior for each of the species. The first activity to help fill in the field guide was to make observations on the morphology as well as the behavior

of the creatures. After the first day of general observations, three days were allotted (one day per creature) to make extensive observations and fill out the respective species' creature page. At the end of each of these three days the class was to name the particular species. To do this each group was allowed to choose a name, within their group, to submit to the class and then the class as a whole voted on the name to be adopted for that creature.

After the first four days the students were briefed on how to collect data to estimate the population. Since the goal here was not to teach population estimation techniques but rather to use population estimates to show interspecies dependencies, the students were only told to count the number of creatures on their WallScope without trying to estimate the actual population. A pattern would arise regardless of extrapolation of the population and that a more complex population estimation method would require more time.

During the next several days, students continued to collect and share their population sample numbers in hopes of discovering a pattern leading them to concluding possible predator-prey relationships. Along with this the students were also told to closely observe the WallScopes to observe predation first hand. At the end a class discussion as to the classification of each species took place. This discussion marked the completion of the field guide however two more days were allotted to discovering migratory patterns of the creatures. This is when the students were first told that the class next door was also doing the same thing and that the creatures might be travelling back and forth. To test this, on the first day the students were allowed to tag the creatures with WallScope-unique tags and make a note of the number of creatures they tagged. On the second day the students returned to their WallScopes to note creatures which had migrated from one WallScope to another, especially animals tagged with WallScopes from the class next door.

4.3.3. Logs & Cameras

The logs recorded the population distribution of the creatures, each repositioning of mobile WallScopes, every WallScope connection, and each time the noise level around a WallScope reached the threshold. Cameras were placed at the back of the class during classroom discussions and then either mounted or carried to follow a specific group during the execution of activities. Though ideally multiple cameras would have followed each group, the necessary resources were not available.

4.3.4. Results

During the species naming activity, the students' naming convention was based heavily on the physical and behavioral characteristics of the individual species (at the adult stage). For example the insect species was named *Sonic* after the popular Sega game character because of its blue appearance and quick movement, the reptile species was named *Slowy* due to its slow speed, and the mammal species was named *Dash*, referring to the fast paced character from *The Incredibles*. Though not scientific in language the underlying thought process is similar to the process that scientists go through when naming and categorizing newly discovered species.

During the 7th grade study, the environmental conditions displayed on the WallScopes did not receive much attention by the students. However in the 4th grade study the students in the mobile instruments class actively and enthusiastically asked for the instruments and noted the temperature and humidity in their field guides. This was most likely the result of having to obtain, apply, and share these devices. They became commodities that warranted attention as opposed to "wallpaper" on the WallScope. This attention resulted in the increased use of environmental conditions (mainly temperature) as explanations to various observations. For example a student attributed the drop in *Dash* population to hibernation during cold weather. The same excitement for gathering environmental data was not present in the 4th grade classroom without mobile instruments.

Students in the class with the mobile WallScopes repositioned the WallScopes an average of 4.1 times per class period. Though raising interest in the activity, the ability to move the WallScopes complicated the task of obtaining population counts due to the variability in populations along the different wall sites.

There was no evidence that showed significant gain in the understanding of population dynamics; however students displayed excitement and motivation during the tagging portion of the inquiry. This was especially evident, by the exclamations made by students, at the end of the unit when they observed previously unseen tags, from the other class, on their WallScopes. The excitement generated by the tagging activity helped maintain the students' interest in WallCology. Due to the implementation of WallCology, the same creature wanders on and off WallScopes, resulting in the recounting of a creature. However when the students utilized the tagging tool, some exclaimed, that "the same [creatures] keep coming back", and thus did not recount those creatures. This led to an increase in the accuracy of population counts.

The 4th grade class (unlike the 7th grade class), did not discover the creatures' sensitivity to noise. This could be attributed to two factors; the creature sensitivity to noise was too high and therefore the creatures were in a perpetual state of "scared" (as recorded by the logs), and secondly the reactions to noise were not as visually dramatic during the 4th grade study as they were during the 7th grade study.

The pre/post tests showed an improvement in associating a creature's morphological feature to its habitat (e.g. body fur with colder habitats, pre-test $M=.34$, post-test $M=.56$, $X^2(1) = .46$, $p<.05$). However associating more subtle morphological characteristics such as scaly skin and body size did not show any improvements. There was also an improvement in students' ability to sequence insect life stages with pre-test $M=.51$, post-test $M=.82$, $X^2(1) = 7.9$, $p<.01$. No gain was seen in the sequencing of mammalian life stages as most of the students were able to correctly order this in the pre-test. Students did not improve in their ability to predict the impact of predator populations changes on prey and vice versa. However most were able to correctly identify the WallCology food web.

Cross classroom collaboration was not fully tested because the study went over the time allotted. The students did observe the migration of tagged creatures between classrooms but did not get a chance to utilize the communication sheets provided in their field guide folders. Students were constantly collaborating with peers within their own classrooms during many of the activities as well as during classroom discussions. Collaboration during activities manifested itself in two ways: task allocation and observation confirmation. During the population counting and tagging activities students were encouraged to divide the tasks within their groups such that there was a recorder, a tagger or counter and an information relayer. Students found tagging enjoyable and so would rotate this task. The other collaboration occurred when disputes in observations arose. The students would try to consolidate the discrepancies with further observations and discussions. For example during one of the counting activities a student counted 42 *Dashes* and other students in the same group counted only five. After a group discussion the group established that the student who counted 42 was counting for a longer period of time than the rest of the students in that group.

5. IMPLEMENTATION

5.1 Overview

WallCology, like other Embedded Phenomena (Moher, 2006), is a client-server application. The server, Phenomenon Server, written in Java, is responsible for most of the simulation's computation and management. It also provides means by which to control the simulation during runtime. The client, WallScope, written in Macromedia Flash ActionScript 2.0, represents the user's view of WallCology and is made up of two key elements: graphic models and ActionScript code. Communication between the server and client takes place over the internet using XML messages. WallScopes utilize iButtons™ and USB iButton Readers to allow the user to position/reposition the WallScope at various predetermined locations along the wall. Mobile instruments coded in HTML and JavaScript represent two distinct measuring tools: a thermometer and a hygrometer.

5.2. Server: Phenomenon Server & WallCology Server

5.2.1. Virtual Environment

The virtual environment of WallCology is made up of Walls which are further broken down into GridNodes. A Wall is represented as a multiply linked list of GridNodes (Figure 4). Each GridNode, along with uniquely identifying information, has a temperature and humidity value associated with it as well as six possible links: up, down, left, right, in and out. A creature within a GridNode can only travel to another GridNode if the two GridNodes are linked. The GridNode links are enforced such that if GridNode A is linked to the left of GridNode B then GridNode B is linked to the right of GridNode A. The implementation of the GridNode allows for many different configurations of the virtual environment. One such configuration, shown in (Figure 5), allows for distant (or not so distant) users to virtually share borders, thus creating virtually adjoined spaces (Figure 6 & Figure 7).

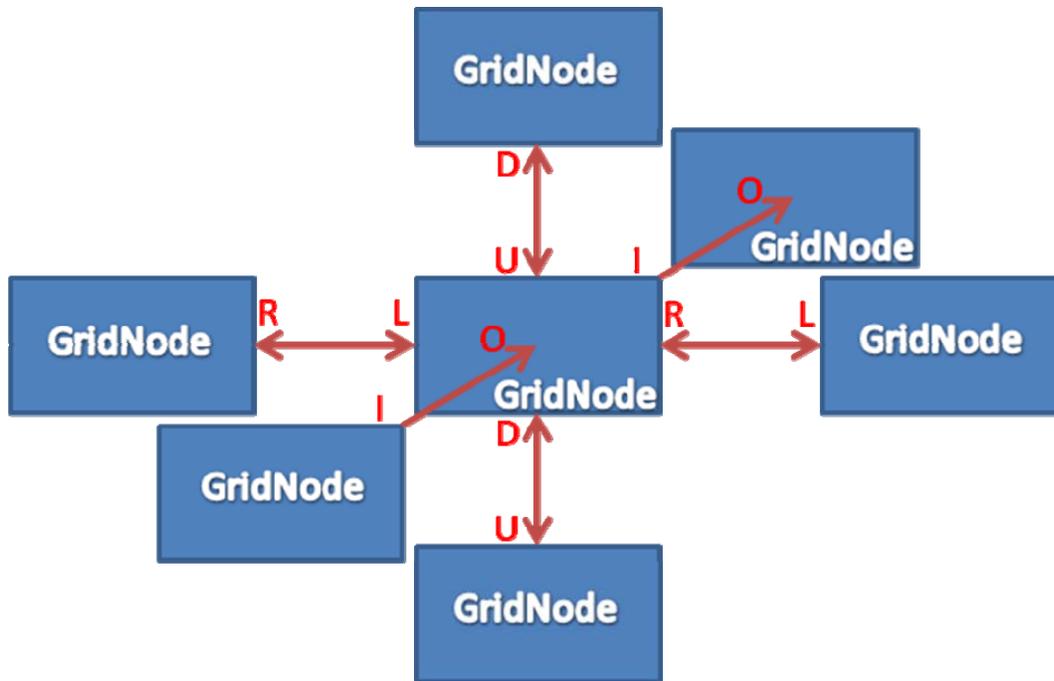


Figure 4: Shows a fully connected GridNode where R=right, L=left, U=up, D=down, I=in and O=out. Most GridNodes do not have connections at either the in or out links.

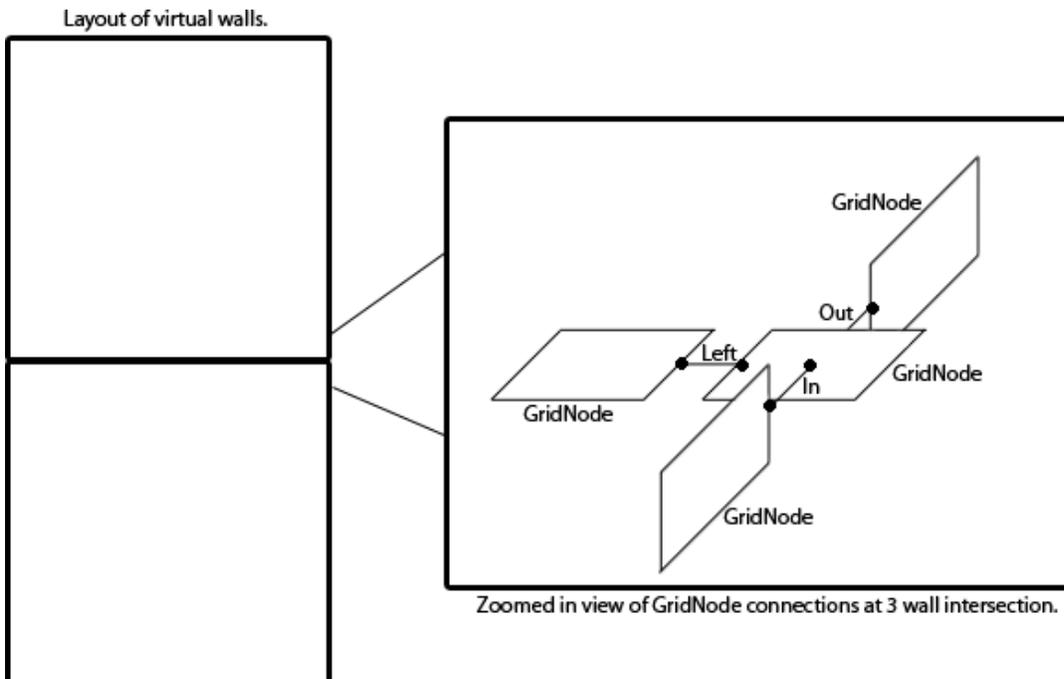


Figure 5: Shows the virtual environment configuration as a whole and a zoomed in view of the GridNodes at the three wall intersection. There are also up and down connections, but these are not shown to simplify the diagram.

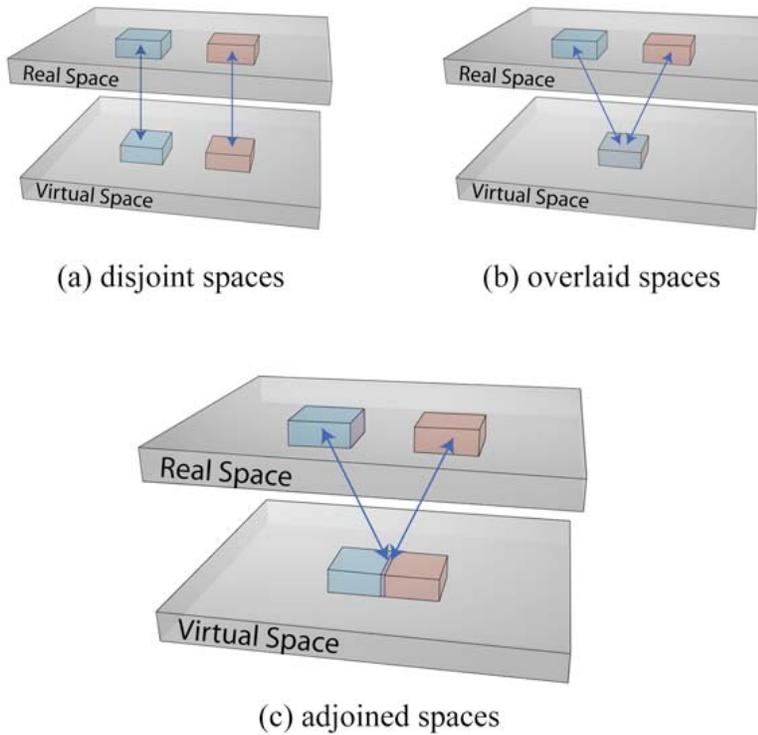


Figure 6: Shared virtual spaces. (a) separated both virtually and physically (b) separated physically but within the same virtual space (c) separated physically but allowed to share borders of the virtual space.

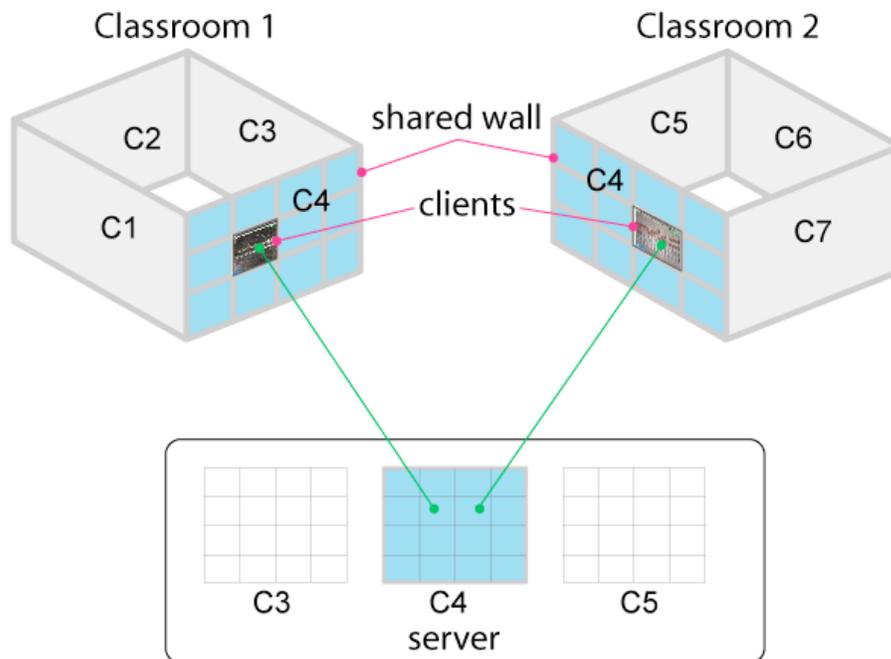


Figure 7: Shows the server and client configuration to support collaborative investigation. Wall C4 is the shared wall in this configuration.

5.2.2. Agents: Creatures

WallCology is an agent based simulation. The environment of these agents has been described above. This section will discuss the properties of these agents. The agents in WallCology are virtual representation of creatures. Each creature is born, goes through its specific life cycle and eventually dies. Creatures have environmental preferences and therefore migrate to locations with more preferable conditions. Each agent is individually updated during the update cycle; this cycle is discussed in detail in section 5.6.

Three different life cycles were implemented in WallCology 2.0. The insect life cycle has four stages: egg, larva, pupa and adult. The reptilian life cycle has only two distinct stages: egg and adult. The mammalian life cycle only had one stage, adult. To introduce variability in each of the stages (besides egg), the size of the animation shown on the WallScope depended on the age of the creature so that the younger creatures would appear to be smaller than older creatures. A creature's life stage is updated using its age as well as random probabilities.

To animate life cycles on the WallScopes a special handshake procedure between the client and server was implemented. If a creature in a WallScope went through a life stage change the creature was put in a wait queue while the WallScope was notified of the change in life stage. The WallScope would then appropriately animate the life stage change, for example hatch an egg. Once the WallScope was done with this animation sequence, it notified the server, which in turn de-queued the creature. A creature in the wait queue is not updated, thus preventing unrealistic events such as an egg moving off screen while hatching.

WallCology 1.0 did not implement birth or death; however this was necessary in WallCology 2.0 to simulate dynamic populations, life cycles, and predation. These updates required an overhaul creature management system in the simulation (from a static creature array to a dynamic creature array). To

control dynamic populations, WallCology contains a population monitor function that ensures creature populations follow a predetermined pattern. To do this, each creature type has a *goal population* which is updated according to a function dependent on time. (Figure 8) shows the population control system in WallCology 2.0. This system can easily be updated to more complex models by subclassing the PopulationControl class. The population control function limited the occurrence of birth and death. A creature could give birth only if the goal population was above the current population (guaranteeing that no populations exploded unless modeled to do so) and the creature was in the final life stage. Creature death occurred in one of two ways; either a creature died from old age or was eaten. To guarantee that no species went extinct creature death was only allowed if the goal population of the species was lower than the current population. Only creatures in their final life stage were allowed to die of old age. An “old age” is defined for each species and the likelihood of death increases with age past the old age value.

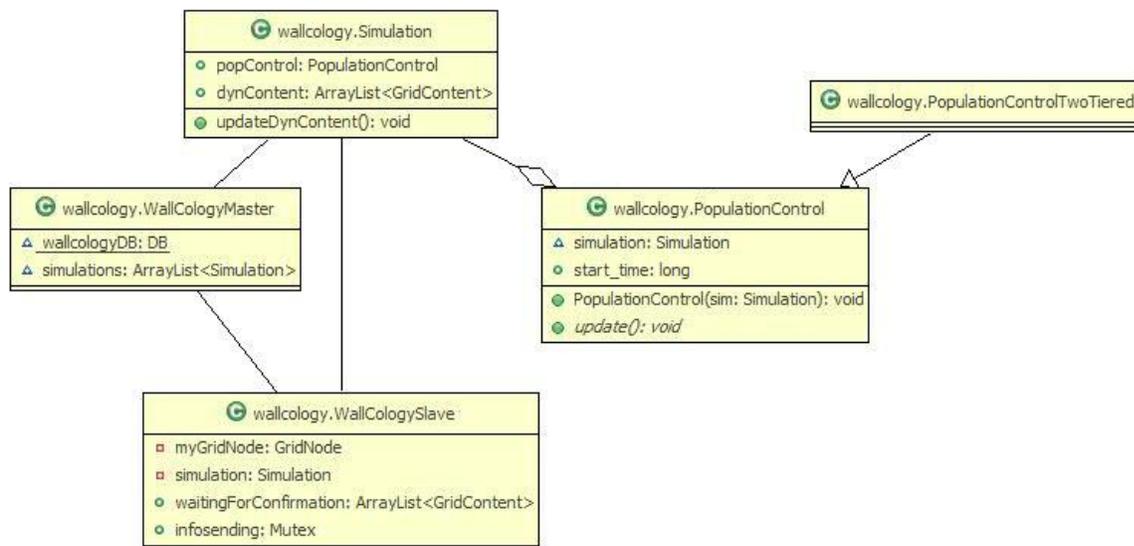


Figure 8: UML diagram for the population control system.

Each creature type has its own temperature and humidity preferences. For example the mammalian creature prefers the cold. Creature preferences and GridNodes' environment attributes allow creatures to migrate, probabilistically, to GridNodes with more preferable environment conditions. The method that determines if a creature will move to a nearby GridNode first assigns preference weights to each of the nearby GridNode as well as the current GridNode. A random “risk” value, which allows the creature to move to less preferred GridNodes, is determined. Using this information the creature will then

decide where to move. A creature may also randomly choose not to move from its current GridNode. Over time higher concentrations of a species will be found in more preferable environments. An administrator can change the values associated with a particular Wall to cause various migration patterns.

5.2.3. Distributed Computation

Thousands of active agents (creatures) can exist within WallCology at any given time and so it is beneficial to reduce the computational load on the server when possible. WallCology does this in two ways. The first technique reduces work by updating only a portion of the creatures during an update cycle. To avoid having a creature remain inactive for too many update cycles, the probability of update is increased each time the creature goes without being updated. The other technique to reduce the servers work load, off loads some of the work to the clients. Since most GridNodes are not connected to any WallScopes, the server only needs to keep track of which GridNode a creature is currently occupying. When a WallScope connects to a GridNode, it becomes responsible for keeping track of local position information. This allows for the server to sleep between update cycles without having the simulation appear to be sleeping to the user since the client will still show that creatures are moving. The server also makes the client responsible for behavior affected by local inputs (currently only noise). This may need to be modified in the future when different inputs are added on the client side. The distribution of computation allows for a far larger number of creatures and WallScopes without significantly increasing the computation load on the server.

5.3. Client: WallScopes

5.3.1. Graphic Models

The graphic models used in WallCology fell under two categories, creature animations and static environment elements. The creature animations were modeled using Maya. These models were designed to resemble real life creatures in response to student comments, from the pilot study, stating that the creatures looked too cartoonish. Video footage of squirrels, bugs and turtles were studied during the creation of the animation sequences to give the creatures more realistic movements. The static

environment elements are the walls and the pipes. To give a coherent look to the WallScopes within a specific wall, background pictures were split up into two separate layers: a layer for the wall and a layer for the pipes. This allows for splicing of the layers in various ways to create many unique but visually coherent environments (Figure 9).

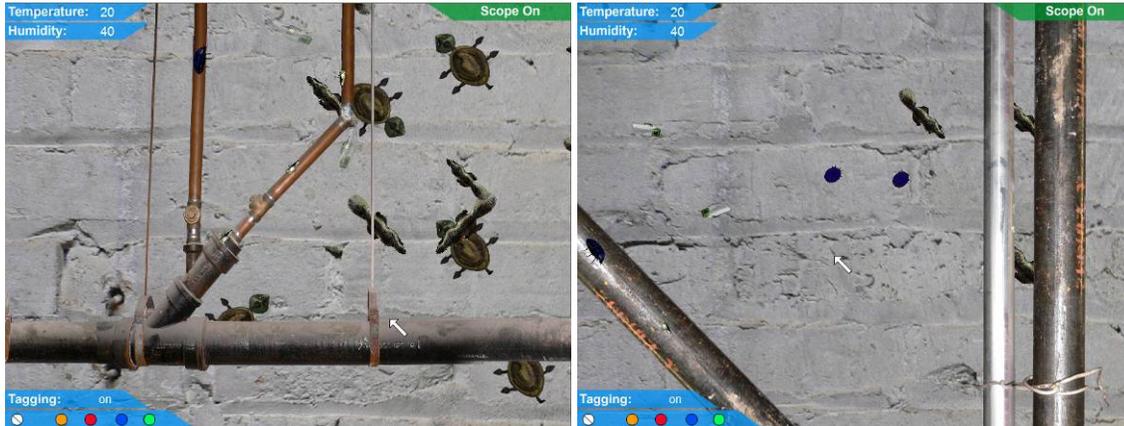


Figure 9: Shows how the wall and pipe layers are spliced to create coherent yet unique WallScope views.

5.3.2. ActionScript

While the graphic models take care of the in-place animation, the ActionScript is responsible for connecting to the server, communicating with the server, managing local creatures, displaying creatures and appropriately moving the creatures. To do this the implementation utilizes a state-based model where each creature in the WallScope is in a particular state. These states vary between species and creature types, an example state diagram is given in (Figure 10) for the mammalian creature, as it is one of the more complex ones. The other state diagrams are similar varying only slightly. Except for the scared state, state changes are triggered by a message from the server.

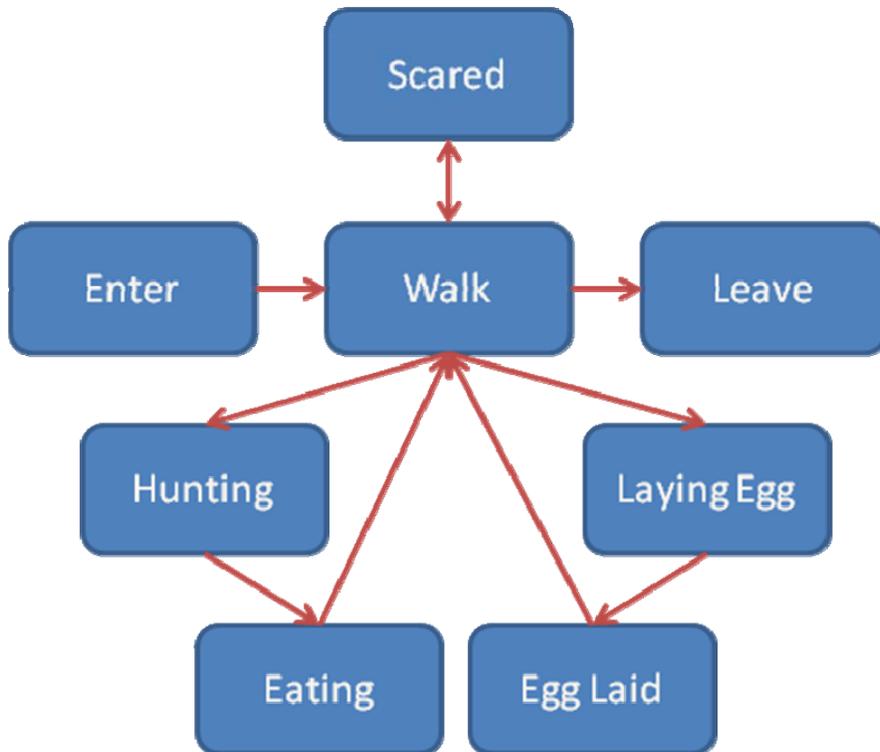


Figure 10: Shows the WallScope state diagram for the mammalian creature.

5.3.3. Tagging

Tagging is almost exclusively handled by the WallScope. The server is notified of new tag creations so that tags persist across WallScopes. To distinguish tags created in one class from tags created in another, two different sets of tags were used: square and circular. Each set was made up of four uniquely colored tags. To tag a creature the user selects the tag color to use and clicks either with a mouse or stylus on the creature requiring the tag. When the user tags a creature, a message is sent to the server notifying it of the tag type and the creature id for the new tag. This tag is saved in the database and associated with the creature with the provided id. Since tags are associated with creature ids, they are also persistent across creature life stages.

5.3.4. Portable WallScopes

To allow users to move around and reposition the WallScopes to various locations on the wall, iButtons™ were used. iButtons are tiny metallic buttons with a chip inside. This chip holds a number that

uniquely identifies the button. One way to ready this information into a computer is by using a USB iButton reader. Unfortunately we were not able to find a way to interface the reader directly with Flash, so we used a Java-Flash Bridge (<http://sourceforge.net/projects/javaflashbridge>) and a small Java application to achieve an indirect interface between the iButton reader and Flash. The Java application communicated with the USB reader using an API (http://www.maxim-ic.com/products/ibutton/software/1wire/1wire_api.cfm) provided by the manufacturer and communicated with the Flash application using the Java-Flash Bridge. Each time the USB reader was plugged into an iButton the id for that iButton was transmitted to the Java application which in turn mapped this id to a particular WallScope position and relayed this information to the Flash application. The Flash application would then use this information to establish a new connection with the Phenomena Server. Each time an iButton was disconnected from the reader, the Java application would notify the Flash application to disconnect from the Phenomena Server. The map between iButton id and WallScope location was stored as an XML file and read by the Java application upon loading.

5.4. Mobile Instruments

The mobile instruments were written in JavaScript, thus allowing them to be executed on any platform with a JavaScript enabled internet browser (e.g. PDAs, iPhones and PCs). During the 4th grade study of WallCology 2.0 iPhones were used because their built-in browser supports JavaScript, they are fairly easy to use and are portable. The mobile instruments were not location aware so the students had to manually enter the location of the WallScope of interest using the buttons on the left (Figure 11).



Figure 11: Mobile instrument thermometer. The letters on the buttons on the left corresponded to various WallScopes which were themselves identified using stickers.

5.5. Communication

In WallCology connections are initiated by WallScopes. To do this, the WallScope sends a connection message, which identifies the GridNode of interest, to the server. The server in turn responds by sending initialization message back to the WallScope. This message contains information that tells the WallScope which background image to use, which pipe image to use, and also the number of creatures currently in that GridNode. Most of the other communication between the client and server occurs in bursts. Each time the server conducts an update cycle, relevant information is sent to the connected WallScopes. This information notifies WallScopes of creatures that have entered, left, preyed upon or died.

5.6. Extensibility: Object Oriented Programming

To allow for an ever growing type of creatures and more complex agents, WallCology uses the object oriented programming paradigm. In the first implementation each creature type inherited its update method from the Creature class because all of the creature types had the same basic behavior: update

location based on temperature and humidity preferences (Figure 12). In the second version, the update method had to take into account varying life cycles and predatory behavior and so the update method (*updateGridContent* found in the Creature class) was broken down into four sub-updates: energy, life cycle, reproduction and location. The update methods within the Creature class call on methods from the CreatureUpdateInterface interface. Each creature type has an instance of a class that implements this interface (Figure 13). In WallCology 2.0, predation is handled by the updateEnergy sub-update method. This method slowly depletes energy from the creature during each update and when the energy is low enough, the creature becomes hungry. When the creature is hungry it will randomly choose to eat preferred prey, which will help it regain its energy. This is a very simplistic view of predation, but more complex predatory behavior can easily be implemented using the structure shown in (Figure 14).

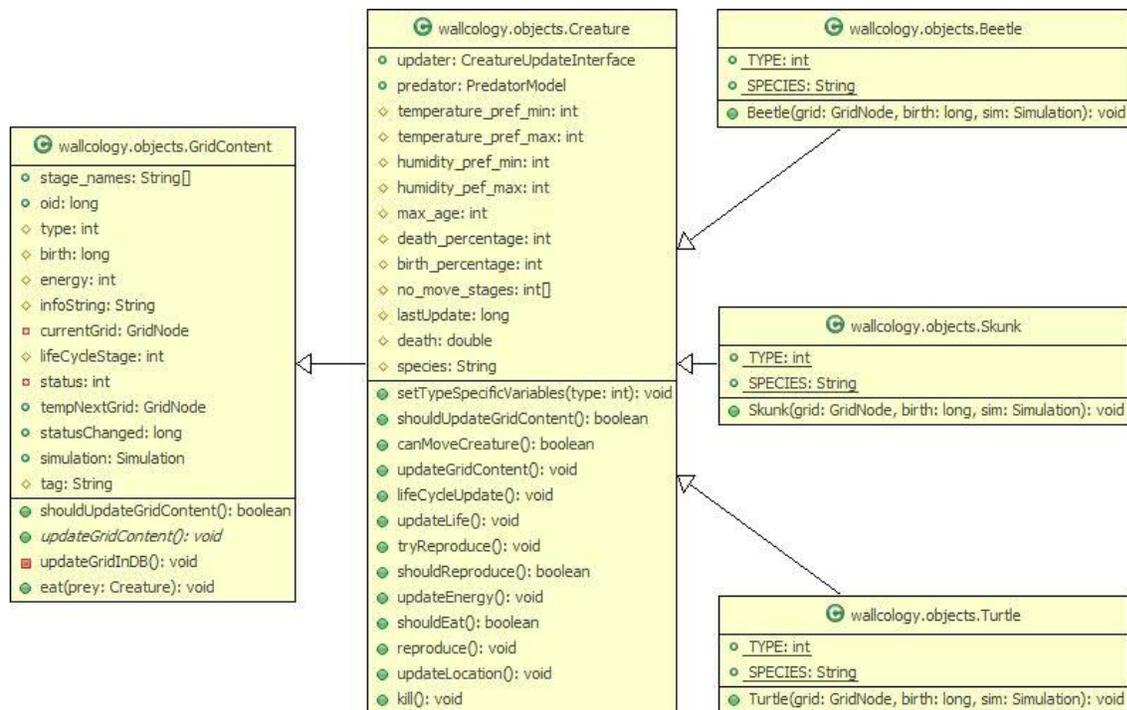


Figure 12: The creature inheritance model. Allows for extensions to be made easily with subclassing.

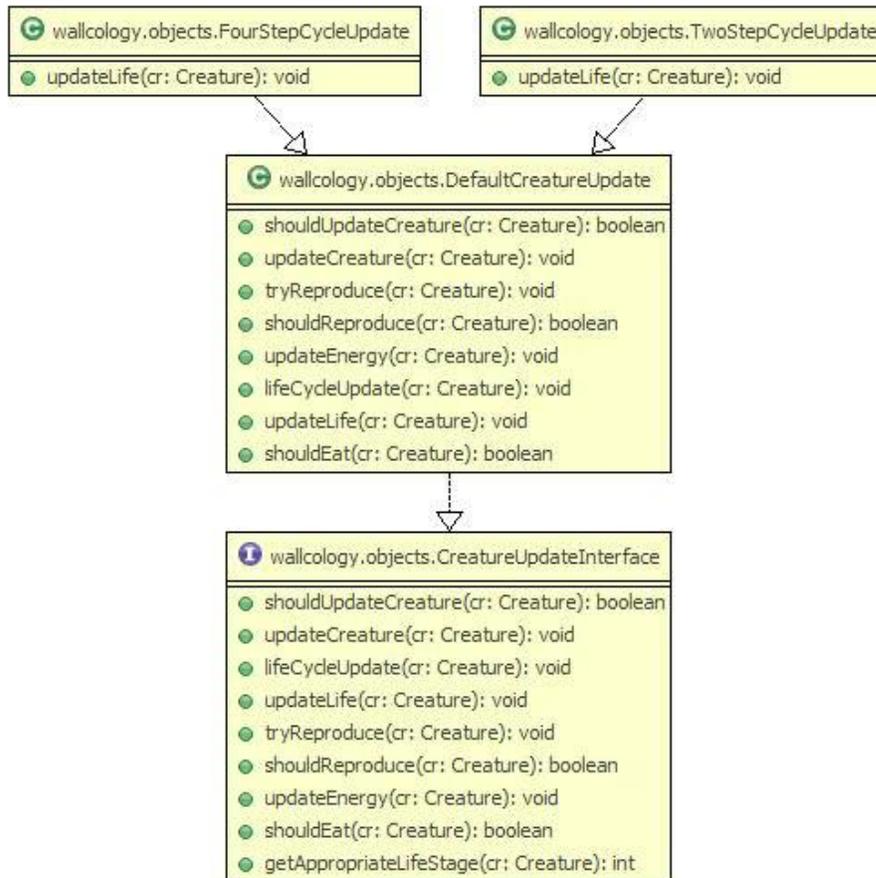


Figure 13: The UML diagram of various update methods. WallCology 2.0 uses the `DefaultCreatureUpdate` method for all creatures. The beetle's & reptile's life cycle sub-update method use the `FourStepCycleUpdate` class and the `TwoStepCycleUpdate` classes, respectively.

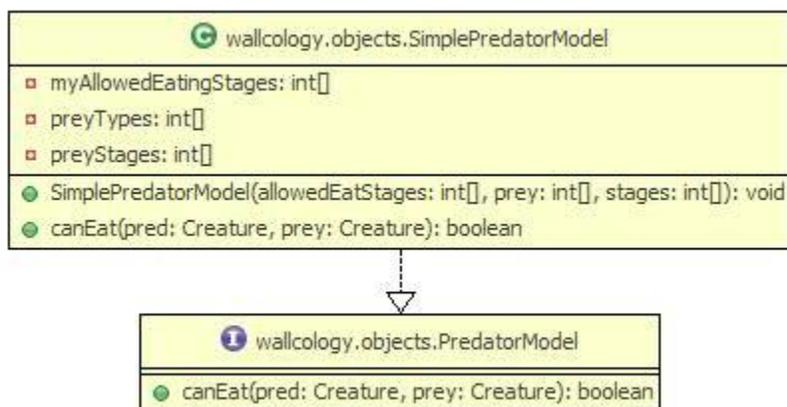


Figure 14: Shows the current predation model, future (more complex) models can easily be implemented without disturbing the creature update method.

6. CONCLUSION

This thesis summarized two iterations of WallCology, currently in its third iteration. WallCology is an evolving learning technology which aims to support scientific inquiry at varying academic levels. We have shown the applicability of WallCology at both 4th and 7th grade levels. The learning goals supported by WallCology activities are derived from standards set by the AAAS and NRC. WallCology provides a distributed virtual environment which supports active science learning and learner cooperation not only within classrooms but also between classrooms.

6.1. Summary of Contribution

This thesis has demonstrated the feasibility of using WallCology in an elementary school setting by careful examination of learning goals, modifications to the initial version of the system, and collaboration with teachers. It has also described three extensions to the Embedded Phenomena framework: (a) portable WallScopes, (b) adjoined spaces, and (c) mobile instruments.

6.2. Limitations

The limitations of WallCology fall under two categories: visual limitations and simulation limitations. The visual limitations of WallCology occur at the WallScope where size is the only variation between creatures of the same type, this leads to visually symmetric creatures. To alleviate this more creature models and randomized “splotches” can be added. Currently WallScopes do not animate predation (though it shows eating, there is no hunting or chasing), mammalian birth, and creature death. Adding these visual representations may increase the apparent authenticity of the simulation, without making the animations photorealistic.

The population modeling algorithm used in WallCology is linear and therefore does not fully capture the complexity of dynamic populations. The simulation also does not accurately simulate predation, death and birth as they are mostly random occurrences, dependent only on the population algorithm. Another limitation to the simulation is that only one WallScope can be connected to a given

location at a time. WallCology also requires a good amount of programming intervention with changes to the learning goals.

6.3. Future work

Many extensions to WallCology have been proposed. The most obvious of these extensions is the implementation of more creature types. Another extension motivated by the results found in the 4th grade study is the addition of various types of mobile instruments. To increase the believability of the WallCology the client may also take into account data from a various inputs to directly affect the creatures. In general, future work should help increase the usability and authenticity of WallCology.

WallCology 2.0 only makes use of three creatures and so there are not enough creatures to create a complex food web. A creature that acts as the base of the food pyramid (like plants) would help make the simulation more realistic. A possible creature of this type could be an “extremeophile” that uses energy from hot water pipes within the walls.

An exciting idea that has been discussed for future implementation is the “cage lab”. This is a mobile instrument that would allow for creatures seen within a WallScope to be captured into a handheld device. The handheld device would allow for detailed tests on the creature, such as blood tests and x-rays, to be conducted. The portable affordances could also be used to affect the simulation. For example a creature injector device could allow students to introduce new creatures or move creatures between WallScopes. Other mobile instruments can enable learners to change the environment of a WallScope. The number of mobile instruments possible is very large and has very interesting implications, as shown by the effects of the thermometer and hygrometer in the 4th grade study.

Like the microphone input currently used in WallCology, more inputs could be used to blend the virtual world with the real one. A simple addition would be the use of web-cams to affect the amount of virtual light in the WallScope. The creatures could react to this in much the same way as the sound input. Almost any other inputs that take real world values and make them available to the computer could be

used to correspond to the virtual counterparts of these values. For example a thermometer could be used to make the real world temperature around a WallScope become the virtual temperature for the WallScope. For example students could use buckets of ice to cool the temperature around a WallScope.

To increase the usability of WallCology, for teachers, an interface needs to be created that can allow teachers to configure the phenomenon to suit their needs. For example teachers could choose the species, the food web and the population model used to best reflect their learning goals. Many updates in the simulation can be made to create a more authentic experience. One of these updates can improve the population model used in WallCology 2.0 to more closely reflect the population dynamics that exist in the real world. Predation can be updated to factor in risk and energy gained. Other updates like mating patterns and flocking can also be incorporated to model the real world and introduce brand new scientific activities.

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APPENDECIES

APPENDIX A: Blank Field Guide**WallCology Field Guide**

Species Name: _____

Life cycle (how they grow)	
 child	 adult

Morphology (body characteristics)

Habitat (where they like to live)		
Physical description	Temperature	Humidity

They like to live there because...		

Behavior (how they act)

APPENDIX A: Blank Field Guide (continued)**WallCology Field Guide**

Species Name: _____

Life cycle (how they grow)		
		
egg	child	adult

Morphology (body characteristics)

Habitat (where they like to live)		
Physical description	Temperature	Humidity

They like to live there because...		

Behavior (how they act)

APPENDIX A: Blank Field Guide (continued)**NTA WallCology Field Guide**

Species Name: _____

Life cycle (how they grow)



egg



larva



pupa



adult

Morphology (body characteristics)

Habitat (where they like to live)

Physical description

Temperature

Humidity

They like to live there because...

Behavior (how they act)

APPENDIX A: Blank Field Guide (continued)Scientist Collaboration Sheet

From: _____

To: _____

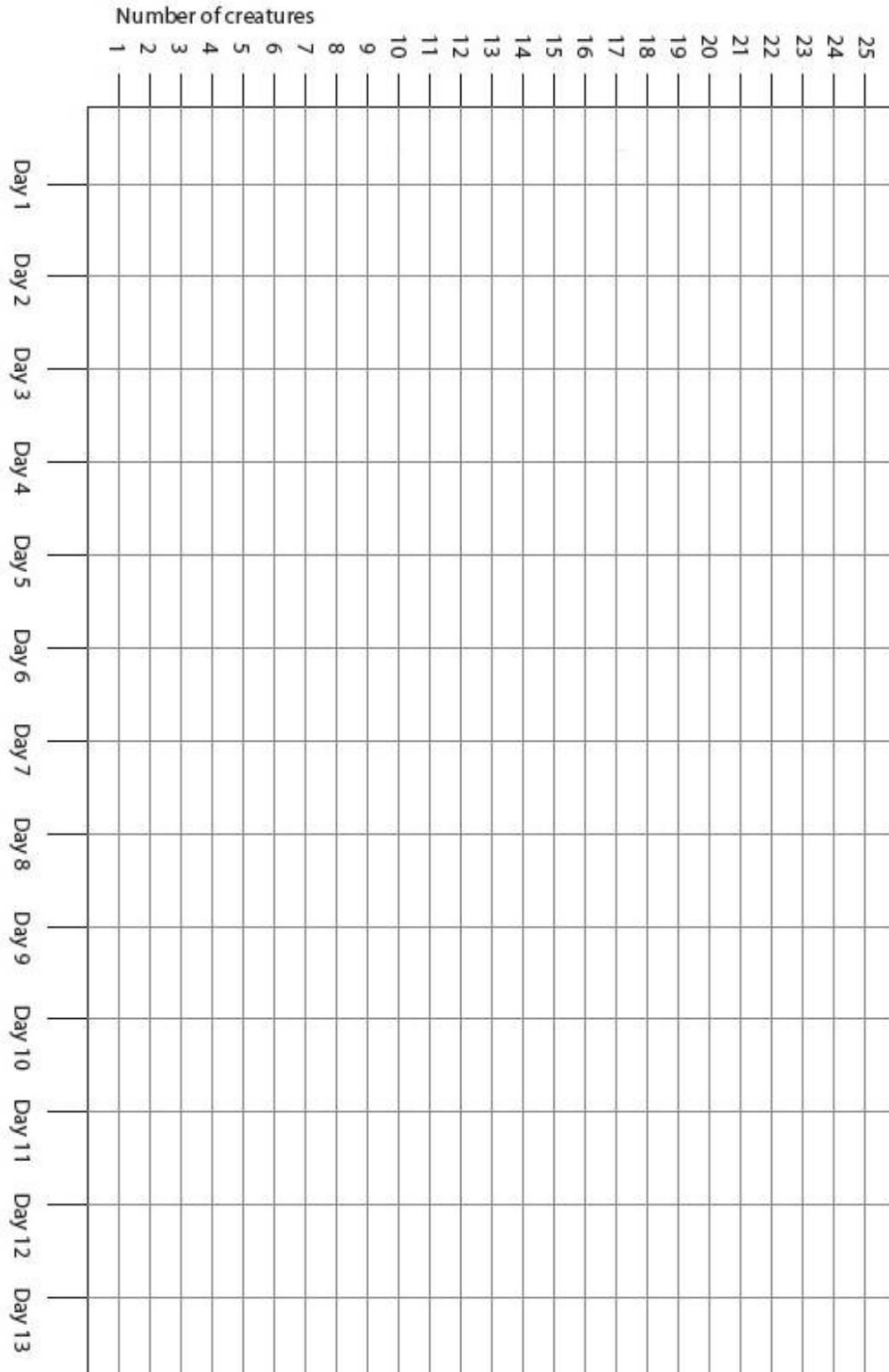
Observations (what you saw):

Actions (what you did):

Questions (what you want to know):



APPENDIX B: Class Graph



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Moher, T., Uphoff, B., Bhatt, D., et al.: WallCology: Designing Interaction Affordances for Learner Engagement in Authentic Science Inquiry. *Submitted for Publication, SIGCHI Conference on Human Factors in Computing Systems*, 2008.