

WALLCOLOGY: A LEARNER'S INTERFACE TO A  
PERSISTENT VIRTUAL ECOSYSTEM

BY

BRIAN ERIC UPHOFF  
B.S., University of Illinois Urbana-Champaign, 2005

THESIS

Submitted as partial fulfillment of the requirements  
for the degree of Master of Science in Computer Science  
in the Graduate College of the  
University of Illinois at Chicago, 2007  
Chicago, Illinois

## ACKNOWLEDGMENTS

I would first like to extend my thanks and deep gratitude to Tom Moher. His ideas inspire me and his passion for learning has helped educate countless people including myself. If it were not for his hard work developing many cross-discipline concepts between computer science and education, specifically Embedded Phenomena, my thesis would not have been possible. He has been a phenomenal (pun intended) mentor and a caring friend.

My parents, Roger and Liz, bestowed on me every possible benefit a child could have and extended caring hands whenever I have been in need. They have given me all the love two parents could offer and have instilled in me the value of hard work and education. I owe them everything and love them more than words could possibly convey.

Mike Barron and Mark Thompson's work on RoomQuake, RoomBugs and HelioRoom, as well as the web-based interface, laid the foundation for my own work on WallCology. I am in debt for all of their hard work. Thank you, guys.

Countless hours of work at the Electronic Visualizations Lab were made inspirational and fun by the men and women who I was fortunate to work with. I would like to thank Dat Tran for offering expertise and methods beyond my own knowledge; Marco Bernasconi and Laura Wolf for providing numerous moments of levity; Vicky Cain and Peter Malcolm for doing so much tedious work for everyone's benefit; Jason Leigh, Ugo Buy and Andy Johnson for passing me years of experience in novel and interesting ways; and most importantly Brenda Lopez for her hard work on WallCology's graphics as well as guidance throughout my time at EVL.

## **ACKNOWLEDGMENTS (continued)**

I would also like to thank Amani Abuhabsah and her students who made the WallCology experience work in the classroom. Also, without the people of SKIT I would not have had the opportunity to work in such an environment nor had the necessary skills to be productive in an urban classroom setting. I owe you much and I hope that your experience was as exciting and educational as the experience you gave me.

Finally I would like to thank Darshan Bhatt who worked along side me in the creation of WallCology. From conception to deployment WallCology is as much his as it is mine. His ideas and design skills were integral in the development of the system. I truly could not have done it without him.

BEU

## TABLE OF CONTENTS

<b><u>Chapter</u></b>	<b><u>PAGE</u></b>
1 CLASSROOM SCIENCE .....	1
1.1 Educational Motivation .....	1
1.2 Access .....	6
1.3 Active Science.....	8
1.4 Cooperation and Collaboration .....	10
2 LITERATURE SURVEY.....	13
2.1 Ecology Modeling & Simulation .....	13
2.1.1 NetLogo .....	13
2.1.2 StarLogo & StarLogoTNG.....	16
2.2 Learning in Computer Aided Environments.....	17
2.2.1 Participatory Simulations.....	19
2.2.2 Embedded Phenomena.....	20
2.3 Ecology Learning Environments.....	21
2.3.1 Savannah .....	21
2.3.2 Ambient Wood .....	22
2.3.3 Hunting of the Snark.....	23
2.3.4 Environmental Detectives .....	24
2.3.5 RoomBugs.....	25
3 USER'S VIEW OF WALLCOLOGY .....	28
3.1 The simulated environment.....	29
3.2 The simulated creatures .....	30
3.3 Interaction affordances .....	33
4 ARCHITECTURE & DESIGN .....	34
4.1 Server Architecture Overview.....	34
4.2 Client interaction with the Server.....	35
4.3 Client Architecture .....	36
4.3.1 Graphics .....	36
4.3.2 Control Structure .....	37
4.3.3 Utility Control Classes.....	38
4.3.4 Creature Class Hierarchy .....	39
4.3.5 State Based Animation.....	42
5 PILOT STUDY .....	44
5.1 Subjects.....	44
5.2 Instruction Method .....	44
5.2.1 Species Differentiation.....	45
5.2.2 Population Estimation.....	48



**TABLE OF CONTENTS (continued)**

<b><u>Chapter</u></b>	<b><u>PAGE</u></b>
5.3 Data Sources .....	52
5.3.1 Pre/Post-tests .....	52
5.3.2 Field Guides, Journals, & Classroom Video .....	52
5.3.3 Post Interviews .....	52
5.4 Results and Findings.....	53
5.4.1 Species Differentiation.....	53
5.4.2 Population Estimation.....	55
5.4.3 Science Attitudes .....	56
5.5 Discussion .....	57
6 CONCLUSION.....	60
7 CITED LITERATURE.....	63
APPENDICES .....	66
APPENDIX A: Species Differentiation Assessment .....	67
APPENDIX B: Student Interview Questions .....	70
APPENDIX C: Field Guide.....	71
VITA .....	73

## LIST OF FIGURES

<b><u>FIGURE</u></b>	<b><u>PAGE</u></b>
Figure 1 WallScope interface running on a tablet PC grants access to WallCology's virtual ecosystem. ....	2
Figure 2 A NetLogo Application showing GUI elements and representation of environment. ....	14
Figure 3 Screen capture of the RoomBugs user interface. ....	26
Figure 4 Two of five WallScopes affixed to walls in the pilot study: in the front of the class below a chalkboard near the teacher's desk (left) and next to the door below the light switch (right). ....	28
Figure 5 Screen capture of a WallScope displaying the local contents of the larger virtual space of WallCology. ....	29
Figure 6 Characteristics of WallCology creature populations. Creature images are scaled proportionately. ....	31
Figure 7 The WallCology 2-tiered approach. The server manages the larger virtual environment and database while clients manage the graphics and user-interface. ....	35
Figure 8 WallCology Client Messaging Protocol. ....	38
Figure 9 UML class diagram of the Creature hierarchy. ....	42
Figure 10 WallCology Field Guide Page. ....	48

## SUMMARY

This thesis presents the motivations, inspirations, design and architecture of an ecology learning environment for middle school science classrooms. The application, *WallCology*, places a virtual ecosystem within the walls of a classroom, drawing from ubiquitous computing concepts. The system is designed to give learners easy access to affordances for the study of ecological phenomena as ecologists would in the field. Using a set of computers as portals into the virtual ecosystem, students study creatures with different morphologies and behaviors moving about on pipes and walls. These portals, called WallScopes, are linked together using a remote server which allows the creatures to move within the larger virtual space based on their own environmental preferences. A two month pilot study of WallCology in an urban middle school classroom comprised of species differentiation and population estimation units demonstrated the feasibility of this approach.

The interactions of Earth's inhabitants have given rise to a wide variety of ecological principles and methods of study and many are not readily accessible for study in elementary school classrooms. As teachers strive to produce scientifically meaningful activities which promote ecology learning for their students, they are often required to work within the space of their classroom because of the logistical and financial constraints involved in taking a group of students into the field. Often teachers bring flora and fauna into the classroom for study but the inherent lack of control can make study difficult. Additionally the removal of such organisms from their natural habitat inhibits the learning of "in the field" ecology principles. WallCology seeks to provide a platform for studying many ecological principles by placing a controlled

## SUMMARY (continued)

virtual ecosystem that is readily accessible for everyday use within the confines of elementary science classrooms.

Ecology in the field is widely observational and seeks to limit the impact by scientists on natural habitats. Additionally, ecologists can only view a sample of the overall system at any one time, thus science requires meticulous data collection as well as collaboration with other observers to gain an overall perspective. These are principles that are difficult to teach with textbooks and can be better taught through practice. The computers of WallCology offer only small samples of the overall space at observational “sites” and thus correlate directly to these principles.

WallCology is built on the embedded phenomenon framework (Moher, 2006) and extends many of its ideas. Previous embedded phenomena have mapped scientific phenomena to the interior of a classroom. WallCology modifies this idea slightly by mapping the phenomenon of an ecosystem to the unseen space between the walls of a classroom. This small distinction in setup lends well to the incorporation of multiple classrooms. Past embedded phenomena have been largely task based and directed at specific curricular goals. WallCology was initially conceived as a platform for teaching many ecological principles and its architecture has been designed for extension and code reuse. The initial implementation, which aimed at species differentiation and mobile population estimation, can be extended to include food webs, life cycles, evolution, and other ecological principles increasing the duration from weeks to months and possibly years of study by elementary learners.

## **SUMMARY (continued)**

The following chapters of this thesis are organized as follows. Chapter 1 discusses the educational motivations of the WallCology system. Chapter 2 is a literature survey of the computer science concepts surrounding WallCology as well as relating systems. The user's view of the WallCology system is explained in chapter 3. The architecture and design of the system, emphasizing the client-side, are given in Chapter 4. An eight week pilot study and its findings are discussed in Chapter 5.

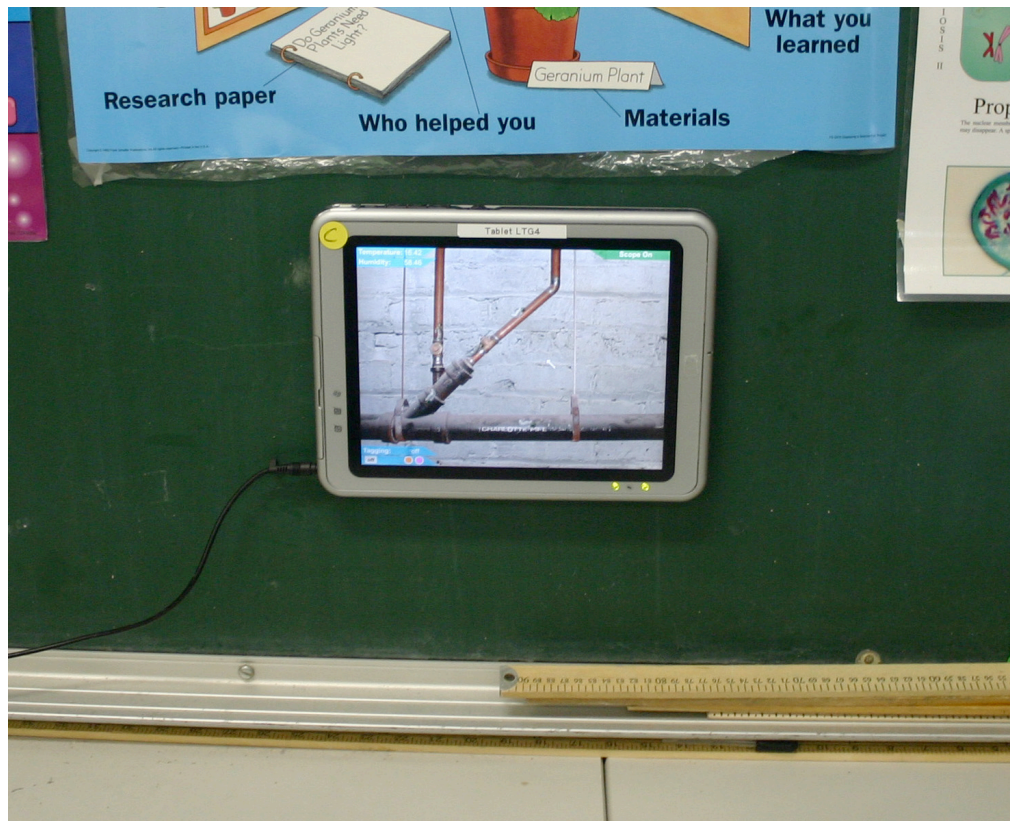
# 1 CLASSROOM SCIENCE

## **1.1 Educational Motivation**

The American Association for the Advancement of Science (AAAS, 1993) and the National Research Council (NRC, 1996) expressed the need for activities which promote the learning of a deeper understanding of scientific principles. To promote this more inquiry-based approach to science education, educators must provide content-rich environments and activities that encourage student observation, investigation, experimentation and theory articulation. Educators are challenged to produce these scientifically rich activities. This is a difficult task, especially when the phenomena are not locally available. Recently, computer technologies have been used to represent various “hard to reach” phenomena for the purpose of inquiry learning. This thesis presents WallCology, a system for studying simulated mobile populations in a classroom setting. In the field, mobile populations are studied through sampling subsets and subsequently drawing conclusions about the larger population from the acquired data. This is necessary since ecologists rarely have access to entire populations. In keeping with these methods, WallCology provides content-rich samples of a larger population through the use of computer technologies.

The WallCology learning experience uses a ubiquitous computer simulation to bring the scientific phenomena into the classroom for study. From the students’ perspectives, they are surrounded by a complex virtual ecosystem that has been thriving within their classroom’s walls unbeknownst to them. A newly developed technology, called a “WallScope,” now grants access to the ecosystem which is filled with virtual fauna. The WallScopes are tablet computers running the simulation which have been attached to the walls and now act as local portals into a larger,

imaginary space behind the walls. The simulation runs continuously, concurrent with regular classroom day-to-day activities, but becomes the center of attention as collaborative inquiry activities, such as the building of field guides based or estimating populations, are undertaken by the students.



**Figure 1** WallScope interface running on a tablet PC grants access to WallCology's virtual ecosystem.

Simulations of populations typically provide users with a complete view of a self-contained environment. This approach grants full access to the state of the simulated phenomena which can be helpful in directing attention to desired simulation parameters. However, a “full access approach” does not afford opportunities to problematize the inquiry processes associated with the characterization of population characteristics when observations are limited to samples of the

larger population. What is the relationship between this sample and the larger population? Are all species present? Is the numerical distribution of the sample representative of the distribution within the larger population? How do additional samples at different temporal and spatial locations impact population estimates? Questions of this type are important elements of an elementary student's understanding of the observational science process (AAAS, 1993; NRC, 1996).

The National Science Education Standards state:

*“Inquiry is central to science learning. When engaging in inquiry, students describe objects and events, ask questions, construct explanations, test those explanations against current scientific knowledge, and communicate their ideas to others. They identify their assumptions, use critical and logical thinking, and consider alternative explanations. In this way, students actively develop their understanding of science by combining scientific knowledge with reasoning and thinking skills” (NRC, 1996).*

Furthermore, for students to understand and use the process of science they must participate in activities which “reflect science as it is practiced” (NRC, 1996). Inquiry questions surrounding the study of mobile populations led to the implementation of affordances within WallCology to conduct a learning experience centered on two ecological principles: species differentiation (the partitioning of observed animals into distinct classes of species based on their characteristics) and population estimation (estimation of full population characteristics from samples). In the spring of 2007, an eight-week ecology unit using this implementation was taught in an urban middle school classroom. The species differentiation unit promotes learning of NRC science standards for middle schools under the content headings of populations/ecosystems, diversity of organisms, and the organism-environment relationship. AAAS standards for middle school mathematics emphasize the importance of developing skills and understanding of the use of



models to represent scientific phenomena. The population estimation sub-unit focuses students on the task of determining population size and requires them to consider sampling and modeling effects on estimation accuracy.

Species differentiation topics are often taught using text, photo, and video aids to introduce learners to the world's organisms and environments. Such methods present information, acquired by ecological scientists, to learners for discussion and comprehension. These methods do not introduce students to the full range of scientific methods used to obtain ecological data or allow the students to conduct the acquisition themselves. Ecologists in the field use morphological, behavioral and environmental data to support differentiation and eventual classification of organisms. This data is a compilation of observations done at various times and in many locations to ensure the observations reoccur and that the derived conclusions are accurate. WallCology presents all of these factors to students so that they may conduct classroom science analogously to how an ecologist would do so in the field.

The topic of population estimation is generally not part of middle school ecology curricula. The times when it is discussed, it often takes the form of worksheets that present mathematical models representing populations and size limiting factors (e.g. predation, food availability). Alternatively, WallCology's approach is to present learners with a situation where they may practice observational science in acquiring their own data rather than simply giving the learners previously obtained data for analysis. After population ecologists acquire data, they use mathematical models to simulate population growth and decline over the course of time but they also estimate population size directly by way of sampling (e.g. census, observational counting,

tag and release). When conducting population estimation activities with WallCology students perform the sampling directly via WallScopes and use the data they acquire in models of their own design as well as models used by scientists.

A pilot study demonstrated the feasibility of teaching both species differentiation and population estimation topics to a middle school classroom using the WallCology embedded phenomenon, but it has been designed for expansion. WallCology is a software platform that can be modified or extended to address a broad range of life science and ecology curricular goals. Currently WallCology is being modified for a second study in two urban elementary school classrooms. This study is set to focus on two new ecological concepts; food webs and life cycles. Since this second study is set to occur in two classrooms using the same simulation, it will also test the cross-classroom collaboration features which were available but unused in first study. The addition of a new capability allowing for discrete position tracking will also enable learners in the second study to choose “where” to place the WallScopes and observe the hidden environment.

Continually building on the WallCology base by adding new creatures, creature relationships, instruments, and environmental characteristics will increase the duration of its use by classrooms and also increase the number of ecological principles it addresses. These extensions will change WallCology from a multiple week activity into a long-term supplemental tool that can be used by educators. With additional content WallCology could be useful year-round in providing an accessible complex ecosystem for study along side other curricular activities.

## **1.2 Access**

WallCology's simulated ecosystem surrounds the students and makes content for inquiry easily accessible anytime the students are in their classroom. Smith and Reiser (2005) have shown that creating a classroom environment which has access to affordances that promote observational investigation helps students understand the process of scientific investigation. They also conclude that such an environment promotes the scientific practice of using observational data to articulate theories and explanations. Smith and Reiser's conclusions are derived from their observation of students' use of Animal Landlord, a computer-based learning environment which presents users with ecological concepts via video clips. Similar systems creating these types of content-rich environments have been implemented both outside the inside the classroom and have used a variety means to present information for inquiry. Other ubiquitous computing technologies such as the Hunting of the Snark (Price et al., 2003) and Ambient Wood (Randell, 2003; Rogers, 2002) have placed students in an environment outside of the classroom with technologies that deliver content-based on student actions to promote inquiry learning. Embedded Phenomena (Moher, 2006) such as RoomQuake, RoomBugs, HelioRoom and now WallCology embed simulations of scientific phenomena within a classroom setting for study. The simulations of embedded phenomena are also designed for use with an inquiry-based approach to science education.

A central goal of WallCology is to deliver the desired content for investigation in a way that requires minimal teacher setup for use on classroom computers. While there is no standard software package employed by classroom computers, Internet browsers as well as Internet

connectivity are now commonplace. This is why WallCology was designed to run on a variety of browsers. Internet browsers are distributed with or provide means to easily download many different software plug-ins. These plug-ins provide features beyond basic HTML. One such plug-in that is increasingly available is Adobe's (previously Macromedia's) Flash Player. The Flash Player plug-in for browsers supports vector and raster graphics, streaming audio and video, and also a scripting language, Actionscript. Flash plug-ins are available for both Macintosh- and Windows-based Internet browsers making Flash and thus WallCology cross-platform compatible.

WallCology uses a client-server architecture that communicates via the Internet. The front-end client application is written in Actionscript and the backend server is written in Java. With this setup teachers need only to install a single plug-in (often already installed by manufacturers before computer distribution) and type the URL of the client application in the browser. The client application then runs on the classroom computer and communicates with the offsite server. The server maintains the larger virtual environment and also keeps the computational load on the client-side relatively low. The computational capabilities of the server computer can be controlled whereas it is unreasonable to require every client computer in future distributions of WallCology meet higher processor and memory requirements. Although this setup does require classroom computers to have Internet connectivity, it is becoming increasingly available. A study conducted in 2002 found that over 90% of US classrooms already have Internet connectivity (Fulp, 2002).

### **1.3 Active Science**

The activities of science require individuals to perform physical actions in the collecting of data, the analysis of data and the testing of conclusions. In circumstances where the human body does not provide affordances for scientific activity, instruments are used to gain access to phenomena. In the case of field ecology, scientists physically travel throughout an area observing aspects of an ecosystem from various perspectives. Thermometers, hygrometers, gas analyzers, etc. are used to collect environmental data. Additionally, in instances when visual acuity beyond that of the human eye is needed to access phenomena “too small,” “too far away” or with an unobstructed view, access is gained through vision enhancing devices (microscopes, binoculars, thermal-imaging equipment, etc.).

Computer simulation can reduce or eliminate the need for physical interaction, but this detracts from the learning of science as a physical activity and does not promote the learning of instrumentation skills. Clicking a button or typing a command to add fifty milliliters to a solution, for example, does not require the physical skills of measuring and mixing. Past learning technologies using computer simulation have promoted the physical aspect of science in various ways. *Ambient Wood* (Randell, 2003; Rogers, 2002), *Environmental Detectives* (Klopfer et al., 2002), *Savannah* (Benford et al, 2004) and *Embedded Phenomena* (Moher, 2006) require users to move between multiple locations. *The Hunting of the Snark* (Price et al., 2003) requires learners to use tokens and physical gestures to investigate a hidden Snark. *WallCology* is directed at providing more authentic physicality, while still considering technology requirements for classrooms.

During the development of WallCology careful attention was paid to creating an implementation which provided access “sites” for observing phenomena. Each site has environmental characteristics and contains an exclusive sub-set of the larger space’s creatures at any given time. These sites are reflected in each individual WallScope which provides access to the environmental and creature data at one local site during the pilot study. In the pilot study each WallScope was physically attached to the wall and thus only provided access to one observation site. Current work with WallCology aims to allow students to acquire data from multiple sites and not just those with a WallScope physically attached. This includes the creation of separate devices which can be carried to any one of numerous different data sites. In future implementations simulated thermometers, hydrometers as well as the WallScopes will run on separate computer devices allowing the user to select where and when to observe the phenomenon.

WallCology’s creatures wander in and out of visible WallScope sites and move fairly rapidly when they are in view. A given creature may only be visible for 15 seconds and there may be up to two or three dozen creatures on the screen at one time. These qualities require students to coordinate observational efforts and impose (human) memory demands as creatures move in and out of view. Sketching a creature, for example, may require a student to mentally note as many morphological qualities as possible and then recreate them after the creature leaves. Some creatures are unlikely to wander into hostile (e.g. too hot) environments with unfavorable qualities, so students need to move to various locations to view different creatures. Quantitative exercises raise the need for distribution of responsibilities. One student may count one creature

type while other students keep track of others. They may then report the results to a recorder to avoid looking away and missing new creatures.

Work with living creatures requires the use of hand-eye coordination and physical dexterity. Living beings are sometimes not gracious enough to sit still and be analyzed, reacting to human presence, so it is up to the investigator to develop appropriate observation strategies. Population estimation is a task for which many methods have been developed. In mobile population estimation mark-recapture techniques are sometimes employed, requiring scientists capture and mark a group of creatures before releasing them and repeating the process. WallCology provides a simple “tagging” instrument in the form of a stylus pen which can be used to “paint” a colored dot and thus mark creatures. Creatures in the wild will run, hide and change behavior to avoid being marked. WallCology’s creatures move quickly, run off screen, and change behavior when startled, making tagging a challenge.

WallScopes detect room volume levels via built-in microphones. This data provides a student presence cue and is used to impact the behavior of the creatures. Since different species exhibit characteristic with some moving rapidly off the edge of the scope and others freezing in place while blending into the background, students learn to approach the observation points quietly. They often include this reaction to noise as a component of their behavioral descriptions of the creatures when discussing WallCology.

#### **1.4 Cooperation and Collaboration**

A central goal of WallCology is to facilitate cooperative and collaborative learning. Vygotsky found that students working in groups can perform at higher intellectual levels than

when they work alone (Vygotsky, 1978). When observing child development he found that skills generally appear first in social groups, and later they are exhibited on an individual level.

Vygotsky's "Zone of Proximal Development" is the basis of the socio-cultural theory of learning which focuses on using group interaction as a means of individual development. Situations supporting this type of learning have since shown (Johnson and Johnson, 1986; Slavin, 1995) additional cognitive benefits, and a call has been made for the change of school structures and activities to incorporate more cooperative, group-based learning situations (Johnson and Johnson, 1994).

Science is also a collaborative endeavor in which those involved work not only in groups but participate in peer review. Acceptance by the scientific community of new findings is done through journals, conferences and meetings. Many fields of science require remote groups of researchers to work in partnership to understand phenomena. Seismologists at one station, for example, must work with other stations to properly triangulate earthquake epicenters.

Collaboration speeds the acquisition of scientific knowledge. A group of ecologists studying the Amazon and another in the Sahara gain knowledge of the separate environments by discussing similarities and differences. Science activities should thus reflect this collaborative nature by creating situations where cooperation is both needed and mutually beneficial.

Student interaction with WallCology takes place at the periphery of the classroom. A set of computers (five in the pilot study) placed on the walls provide access to the simulation. This physical setup allows students to interact with one computer at a given time but through collaboration they can work as a classroom to interact with all access points. Having separate observational sites allows for the problematization of observational tasks, demanding teamwork



to understand the nature of the full system space. Environmental variations and the reactions by creatures can be understood through observation of phenomena at the various sites and then through discussion of the separate findings. Tasks like population estimation provide situations where groups working at physically-separated sites will benefit from the sharing of data and ultimately arrive at more accurate estimations. Still other tasks, like building a comprehensive field guide or tagging animals, support cooperative learning in that they are too much work for an individual student.

Different classrooms may share the virtual space of WallCology. By placing WallScopes in different rooms and linking them to the same virtual space, classrooms may cooperatively work on tasks and/or discuss their independent findings. Classes may share all or part of the virtual environment regardless of whether the classrooms are physically adjacent. A classroom in Chicago, for example, can share an adjoining virtual space with a classroom in the New York. Cross-classroom collaboration has been demonstrated via learning circles but has previously focused on cultural learning differences (Riel, 1995). Cross-classroom work in the case of WallCology is designed to further support scientific collaboration.

## 2 LITERATURE SURVEY

### **2.1 Ecology Modeling & Simulation**

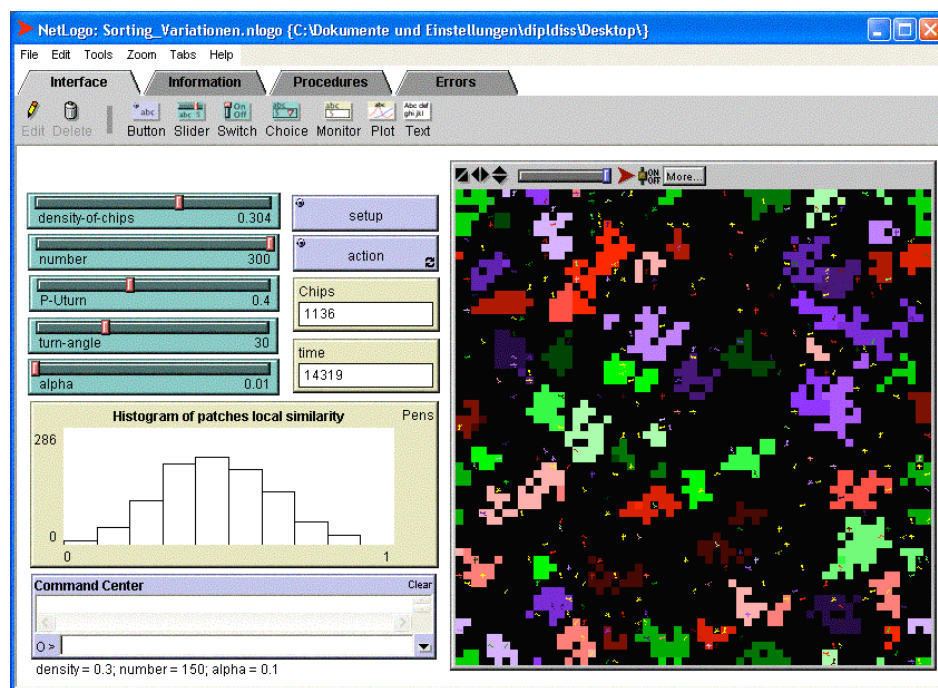
Agent-based modeling software with graphical user interfaces has been widely available since the release of STELLA by iSee Systems (STELLA, 2007). These systems make it possible for users to program agent-based models of their own design. Ecology simulations implemented as large agent-based systems have been used to create a variety of ecology simulations. These software suites require that users have detailed knowledge of the phenomena they are modeling as well as some programming skill.

In these designed models users control the input variables via simple widgets and can view output in graph form or as simple icon representations of the designed environment and its inhabitants. The emphasis is on the model itself and thus the graphical representations of the components (or creatures) are generally basic dots or icons. Due to the complexity of the educational applications and their abstractness, the programs are well-suited for use at the high school or collegiate level but the requisites for use are often beyond that of lower grade level students.

#### ***2.1.1 NetLogo***

NetLogo is a multi-agent programming language and modeling environment based on Java. NetLogo was authored by Uri Wilensky in 1999 and is maintained by the Center for Connected Learning and Computer-Based Modeling at Northwestern (NetLogo, 2007). Downloads of the

developing environment are available as open-source software via the Internet. Since it has been around for over ten years during which it has had frequent use by people in many different fields, current versions of NetLogo are highly stable and run on a variety of computing platforms. The distribution also contains a wide variety of modeled phenomena for reference and testing. The models are of phenomena from scientific fields including biology, chemistry, physics, computer science, earth science, mathematics, networks, social science, and system dynamics.



**Figure 2** A NetLogo Application showing GUI elements and representation of environment.

NetLogo gives programmers the ability to write instructions for individual agents to simulate social and natural phenomena. The individual agents, called *turtles*, interact with each other as well as a shared environment that is divided into subsections called *patches*. The simulations run

in a step/turn-based mode. During each step/turn a set of instructions are executed yielding the output of the model. The user sets the initial conditions via widgets controlling variables and then runs the simulation. Adjustment of the time-step allows users to speed up or slow down the simulation once it is running.

NetLogo's code base includes curricular models such as EACH (Evolution of Altruistic and Cooperative Habits) and EvoLab (Evolution Laboratory). Both of these curricular models are centered on evolutionary biology and include model activities used to explain evolutionary principles. One model, Bug Hunt Camouflage (Wilensky, 2005), is designed to support learners' exploration of the evolution of camouflage through natural selection. (Observations in industrialized England found that dark colored moths flourished in habitats made dark because of pollution since predators could not see the moths that blended into their surroundings and thus ate more of the lighter moths which they could see.) Bug Hunt Camouflage displays an image of an environment (e.g. sea shells) and places colored icons of moths on the image. As the application runs, the moths that are most "fit" for the environment thrive: moths that do not blend into the environment are removed and the ones remaining produce offspring.

Most NetLogo applications do not provide interactivity with the simulation once the initial conditions have been set and the simulation begins, but in some applications a text-based command line tool does allow for the user to call commands on the fly. The models are generally used for only short durations with users changing the conditions once the simulated system stabilizes or a trend in the data is seen and then restarting the model. NetLogo allows users to import images to be used as backgrounds for the world, but a library of symbols/shapes is used

for the agents and patches. The icon-based representation is not capable of showing animated movement or detailed morphologies for individual creatures or other scene elements.

### ***2.1.2 StarLogo & StarLogoTNG***

StarLogo, like NetLogo, models scientific phenomena via agent-based programming. StarLogo was originally called MultiLogo in 1989 when it was in development by Resnick (Resnick, 1996). Current versions are maintained by MIT's Media Lab (StarLogo, 2007a). As with NetLogo, it also allows users set initial conditions via widgets and view icon-based representations of the output. A recent version of StarLogo, StarLogoTNG (The Next Generation), uses three-dimensional modeled graphics and animated movement to show social and natural phenomena. StarLogoTNG also attempts to remove the syntax barrier of the original versions by using a graphical programming interface. To create a model, programmers arrange colored polygons called *blocks* that represent conventional programming instructions.

StarLogo has a slightly smaller code base than NetLogo but still offers several open-source biology, mathematics, physics and social systems models. A repository for StarLogo models is available online through MIT's education department (StarLogo, 2007b). StarLogoTNG, since it is relatively new, has only a few available example applications, mainly in the area of mathematics. StarLogoTNG's movement away from icon-based representations may prove beneficial for use in lower grade levels as young learners may associate a 3D model of a creature to a real-life creature more readily than associating a triangular-icon to a real-life creature. The efforts to make programming more accessible via "code blocks" potentially makes creation of

these models easier for grade school and middle school teachers, but heavy emphasis on programming and ecology modeling is still a necessity.

## **2.2 Learning in Computer Aided Environments**

Paul Milgram, in his taxonomy of mixed reality virtual displays (Milgram, 1994a; 1994b), placed real environments and virtual environments on opposite ends of the reality continuum. As one follows the continuum from real environments, first encountered is augmented reality. Augmented reality systems combine real and virtual environments. Ronald Azuma adds that they must also be interactive and registered in three dimensions (Azuma, 1997; 2001). In contrast, virtual reality (or “virtuality”), according to Milgram, is located toward the end of the spectrum: purely virtual environments. Virtual reality systems seek to replace the real environment with a virtual one where as augmented reality systems seek to supplement the real environment with virtual objects. The replacement of reality in virtual reality systems requires complete immersion in technology. Many applications employ head-mounted displays to replace vision of the real with the virtual. In other instances entire rooms with video displays for walls are used to accomplish the immersion.

Augmented reality, like virtual reality, often uses vision technologies that allow for the addition of objects to a users field of view. These systems are often seen in museums exhibits adding to stationary displays (Woods, 2004). Haptic devices are used by the medical community to prepare for surgical operations in augmented reality before performing in reality. These technologies are not available in K-12 grade classrooms and are rarely available at the collegiate level and thus the learning technologies at the K-12 grade levels have focused on low-tech

solutions as a means of creating augmented reality systems for the purpose of learning.

Milgram's definition of augmented reality has been expanded and now is applied to a wide variety of ubiquitous computing technologies which merge virtual objects or environments with the real.

Mark Weiser summarized ubiquitous computing as the "inverse of virtual reality" in that virtual reality seeks to exclude the real world where ubiquitous computing seeks to embed computers in a real world context (Weiser, 1994; 1999). Ubiquitous computing places computing technologies at the center and periphery of an area and at any time the focus can be shifted easily from one to another. Wireless communication, location awareness, and the use of a broad range of computational and display devices are the technological foundations of ubiquitous computing and can be used to augment reality for the purpose of learning.

Within the past decade the concepts of virtual reality, mixed reality, augmented reality and ubiquitous computing have been used in conjunction with computer simulation to build learning environments for K-12 learners. To varying degrees these learning environments use computers to change/supplement the real environment of the classroom, allowing educators to incorporate scientific phenomena. Regardless of how these environments are labeled, they all create situations for learners to actively participate in scientific inquiry in novel ways which they otherwise would not have access to in their day-to-day classroom activities.

### ***2.2.1 Participatory Simulations***

Participatory Simulations are a type of mixed reality environment that creates a situation where each student takes part in a computer simulation (Colella, 2000). Each participant has access to a personal interaction device that allows them to receive information from or send information to a computer simulation. The actions of each participant effect the overall simulation and thus the experience of all other participants. These characteristics are designed to emphasize the learner's social interactions. At times learners work cooperatively to accomplish a goal while at other times their interactions, as elements of the simulation, unfold to reveal a larger social phenomenon.

Past implementations of Participatory Simulations have used Thinking Tags which are wearable mobile devices. Tags dynamically exchange information with other tags and provide output data to users via simple LEDs and a number pad. This unobtrusive output is meant to provide information without interfering with participants social interactions. In an initial trial simulation, personal data was placed on each person's tag. When two people came in contact, their tags would indicate how much the two people had in common. The information was often used as a means of starting a conversation.

Another simulation done within a high school focused on the social aspect of an epidemic. Learners equipped with tags were challenged to not contract an electronic virus which was passed by social interaction. If they came into contact with someone, as they wandered around the school that had the virus, it could be passed from the diseased tag to the healthy tag. After the simulation ended students were asked to characterize the nature of the disease. Do all those who



come in contact contract it? Does it have an incubation period? Were some people inherently immune to the simulated virus?

Unlike Participatory Simulations learners using the WallCology system interact without a mediating technology such as a tag. Individual users affect other users' results and experience with the simulation but they do so by collaborative investigation. Where participatory simulations make students elements of the simulation in an effort to understand social interaction, WallCology embodies students as scientists who engage in social interaction to study a simulated scientific phenomenon.

### ***2.2.2 Embedded Phenomena***

As stated in chapter one, Embedded Phenomena (Moher, 2006) map simulated scientific phenomena to the physical space of a classroom. Learners observe and modify the state of the simulated phenomena which are accessible via display and control devices placed throughout the classroom. The simulations run continuously over the course of learning activities whose duration may extend to weeks or even months. The simulation runs asynchronously with respect to the flow of day-to-day instruction, but becomes the focus of attention either through instructional sequencing or when state changes in the phenomena demand action.

A large emphasis has been placed on making embedded phenomena as accessible and easy to use as possible in K-12 classrooms by requiring only small amounts of readily available technology. Embedded Phenomena applications use built-in Flash Actionscript because the required players which execute those applications are widely distributed available across

multiple platforms. This makes it possible for the wide variety of computers currently in K-12 grade classrooms to run the applications. The computers used as display/control affordances are linked to an offsite server that coordinates the delivery of the phenomena, requiring internet connectivity. Although past simulations have imposed relatively low computational demands, as more computationally demanding applications are developed, the server-client model can be used to minimize the computational load on each individual classroom computer. WallCology takes advantage of this server-client architecture, placing a large part of the computation on the off-site server.

### **2.3 Ecology Learning Environments**

Recently, ecology computer-aided learning experiences utilizing augmented reality and/or ubiquitous computing principles have moved away from single-user desktop applications like NetLogo and StarLogo. These technologies have been used to facilitate cooperative and inquiry-based ecology learning. Much of the research in this area has been done by the EQUATOR project in the United Kingdom (EQUATOR, 2007). EQUATOR explores mixed reality experiences and challenges of working with these media.

#### ***2.3.1 Savannah***

Savannah is a simulation of lion survival behavior in the wild. Learners act as the lions protecting their young, marking territory, and hunting prey for food. This outdoor location-based game takes place on an open field where learners are free to roam about with mobile computing devices which provide them with information about the virtual savannah that has been mapped

onto the open field (Benford et al, 2004). Users' computers are equipped with GPS tracking and linked to a game server. The information they receive is used to complete a series of collaborative tasks in the mixed reality environment.

The survival tasks are conducted by five students at a time, each receiving sight, sound, and smell sensory data based on their individual location. Students collaborated to achieve their mutual goal. After each mission, students returned to a room called a "den" to review and reflect on the activity.

### ***2.3.2 Ambient Wood***

In Ambient Wood learners enter and explore an outdoor woodland area which has been supplemented with electronic devices (Randell, 2003; Rogers, 2002). Students wander through the environment in pairs interacting with the different ambient devices to receive further information about the area's ecology. During testing, Students were encouraged to discuss the environment with their partner and also a "remote facilitator" (i.e. teacher). The digital augmentation of Ambient Wood includes moisture probes, periscopes with pre-recorded video clips, speakers delivering ambient sounds, and PDAs providing students with images and voice messages.

Ambient Wood is a digitally augmented environment designed to allow users to investigate ecology and part of the EQUATOR project. The mixed reality environment of ambient wood uses ubiquitous and mobile technologies to provide learners with ecology information that would be otherwise unavailable in a quick walk through the woods.

The creators of Ambient Wood devised a framework for digital augmentation which can be used to classify various technologies. Their framework focuses on the type of augmentation (pre-recorded or live) and the mode of delivery (student initiated, environment initiated, or both). Two studies were conducted to investigate the students' interactions and collaborations within the environment and its digital augmentations. The first study concluded that instances where interaction with the technologies was student initiated, produced more "collaboration, reflection and hypothesizing" than technology initiated interaction. The follow up study focused on student initiated interaction by replacing the automatic delivery of information with a means for students to directly request the information. The study found that this setup created more student reflection as well as a higher level of detail in collaboration between students and the remote facilitator.

### ***2.3.3 Hunting of the Snark***

In the Hunting of the Snark, learners entered a cave like environment occupied by a virtual creature: the Snark. The individual rooms of the cave are embedded with tangibles, designed to facilitate learning through engagement, reflection and understanding. As in Ambient Wood, students worked in pairs for a short amount of time but this time the goal was to gather as much information as possible about the virtual Snark. The students saw clues about the Snark manifesting itself through various technologies which, in turn, made the invisible environment visible to the learners.

A handheld PDA device directed learners to various rooms where they could interact with the Snark through tangibles. The pairs were given physical tokens which represented some virtual

manifestation in the Snark's environment. In one room, occupied by only a well, the tokens represented different types of food that the Snark could eat. Based on the Snark's preferences an animation showed that the Snark either liked or disliked the food product. After walking to another room the students were required to use a token to enter. Based on the token used, sounds were played to represent an environment. Sensor pads in the room controlled volume levels and only when the volume was the highest the Snark would appear. A final room used sensor jackets to register various movements as students watched an animation of the creature. Some movements caused the Snark to move from its perch for better observation by the learners.

The collaborative exploration and interaction with the creature led to verbal reflection on what they were doing at the time which was later discussed after the hunt was over. The representations of the Snark and the means of interaction were purposely left somewhat abstract and provided only glimpses of the virtual world, leaving the students to hypothesize about the unknown.

#### ***2.3.4 Environmental Detectives***

Environmental Detectives was originally conceived as a single educational, augmented reality game designed to support environmental science (Klopfer et al., 2002). Using handheld computing devices, students move around the real environment of a watershed (natural drainage basin) and collect data on a virtual disaster in which the area is being polluted. Learners were encouraged to supplement their collected data with other scientific research about the geographical area as well as data on pollution in general to discover the nature and source of the disaster.

Working in groups, students physically move to real-world locations to gather data on the disaster. After gathering data on air, water and soil pollution students head back to a meeting area to discuss their findings and also to view scientific visualizations of the data. Using these tools, students find that the pollution is coming from a small industrial area. They then interview fictional works of the factories and plants in the area to find the culprit.

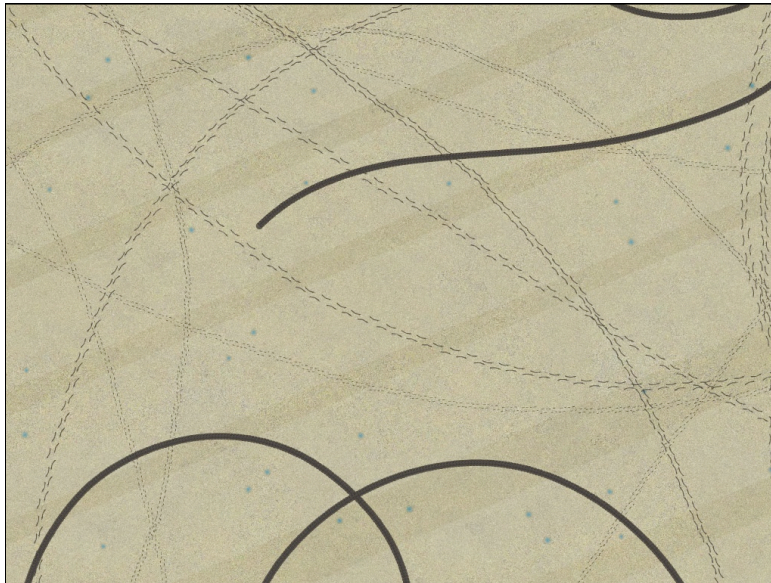
During iterative testing Environmental Detectives grew into a system which now encompasses other virtual disasters and real world locations (Squire and Klopfer, 2007). A toolkit has been created which uses an XML database to store videos, text, images and maps together with GPS coordinates to create new scenarios. During testing, a suburban nature center, which was formally a missile base, was used as the setup for pollutants escaping into the environment.

In Environmental Detectives the media database and local environment provide affordances for science inquiry learning. The addition of a problem (finding the cause of a disaster) provides a driving goal or question for the students to solve.

### ***2.3.5 RoomBugs***

RoomBugs is WallCology's closest relative in the world of ecology learning environments. RoomBugs (Barron et al., 2006) is an embedded phenomenon which places virtual bugs in the classroom for learning through experimentation by the students. The students act as "environmental managers" who control the outcome of the simulation. The virtual environment is viewed through a set of computers which represent sandboxes. As the unseen bugs walk through the sandboxes a series of tracks can be seen. These tracks occur in different

frequencies based on the location of the sandbox and each track identifies one species of bug. Some bugs are beneficial to the environment whereas others are harmful. It is up to the environmental managers to keep the bugs numbers under control, consistent with the needs community's. The community's needs are the driving goals of the phenomena and can only be met through experimentation to understand how the use of virtual pesticides influences the virtual bugs. A pilot study of RoomBugs was conducted in an urban middle school classroom and took three weeks for completion.



**Figure 3** Screen capture of the RoomBugs user interface.

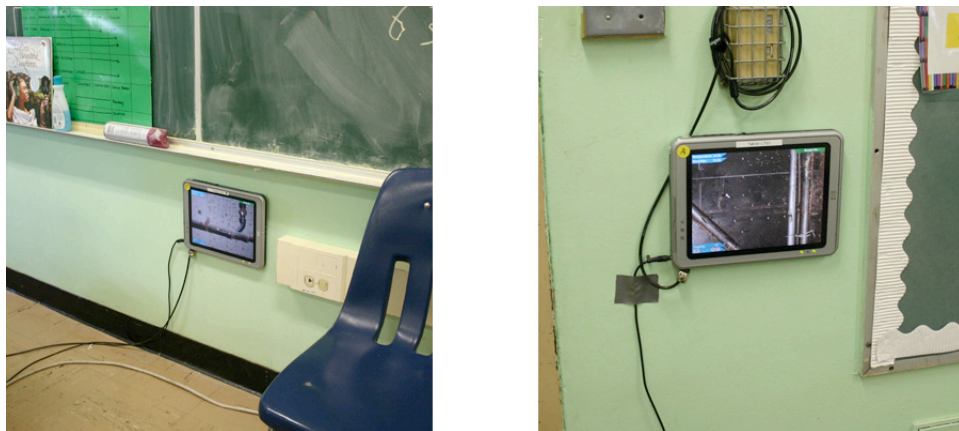
RoomBugs, like other phenomena, runs continuously and is brought to the center of attention when inquiry activities are conducted. Students are given knowledge about their goals, (e.g. which bugs are harmful to the community's crops) and then devise and conduct experiments to determine which pesticides and what spraying methods are the most effective for controlling the bugs.

RoomBugs is used to convey some ecological principles of invasive species to students but really seeks to increase students' abilities to understand and practice experimental science. WallCology's approach is slightly different in that it seeks to focus on many ecological principles and incorporate experimental science when it is a justifiable means to understanding the ecological principle. Students were asked to differentiate the species of WallCology and this task can be seen as a student driven means of acquiring the base knowledge necessary to run population estimation experimentation. This correlates to the background knowledge which is taught in RoomBugs via newsletters and discussions to provide the foundation for pesticide experimentation.



### 3 USER'S VIEW OF WALLCOLOGY

The user interface of the WallCology system is presented on a collection of tablet computers (WallScopes) affixed to the walls of the classroom (Figure 4). On each WallScope, the display is designed to serve as a simulated “direct camera feed” to the unseen space within the walls (Figure 5). The WallScopes run continuously over the duration of the instructional unit, providing simulated views of the local environment and the actions of the creatures in the walls, as well as allowing limited interaction with the creatures. The status of the WallScope is indicated by an overlay in the upper right corner; the WallScope is “on” when the WallScope computer is connected to the server.



**Figure 4** Two of the five WallScopes affixed to walls in the pilot study: in the front of the class, below a chalkboard, near the teacher’s desk (left) and next to the door, below the light switch (right).

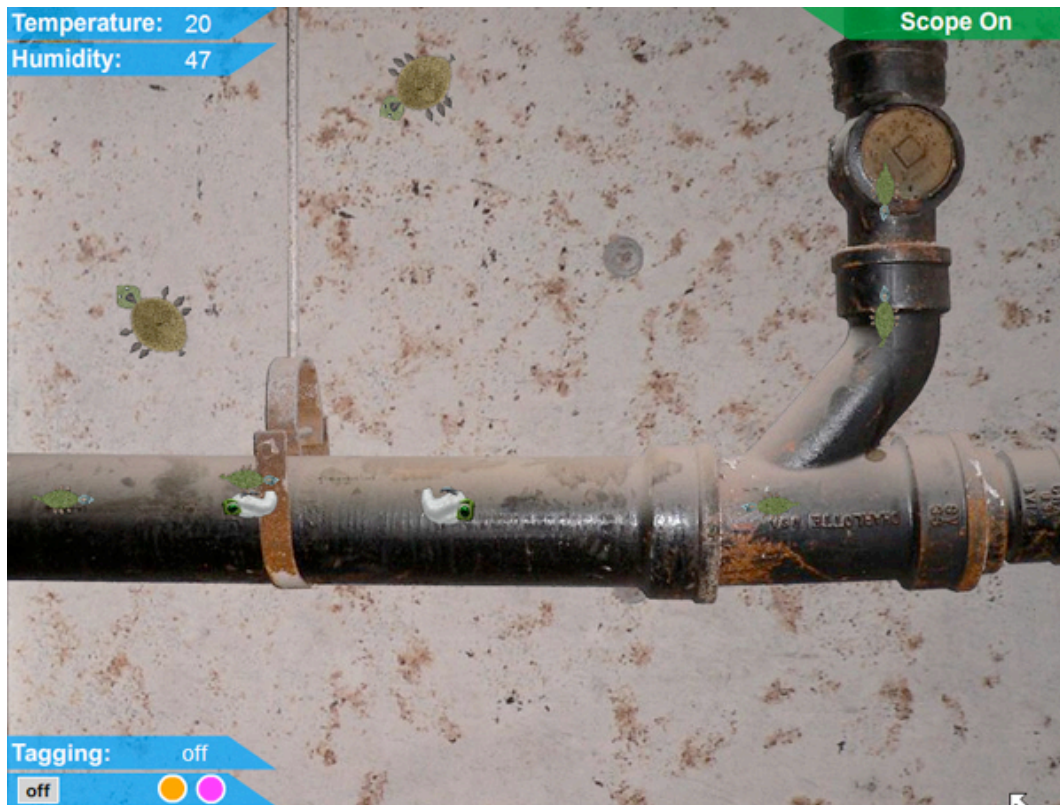


Figure 5 Screen capture of a WallScope displaying the local contents of the larger virtual space of WallCology.

### **3.1 The simulated environment**



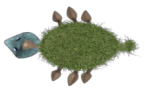
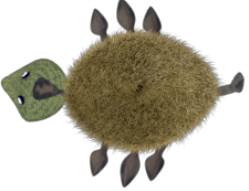
Each WallScope depicts a local environment with unique characteristics. The physical elements of the environment include various configurations of pipes set in front of a background wall representing the boundary with the adjoining room. The images were taken from photographs of an apartment building undergoing reconstruction in an effort to provide a realistic look to the scene. Images of concrete and steel walls provide the background for the scene; a second layer of pipe images is placed upon the background. Combinations of four background

and six pipe images are used in WallCology to provide different scene compositions.

In addition to the structural elements, each local environment is also characterized by the temperature and humidity within the adjoining space. Dynamic temperature and humidity conditions are displayed on a semi-transparent information bar in the top-left corner of the WallScope.

### **3.2 The simulated creatures**

The simulated environment serves as the setting for a collection of animated creatures. The creatures, while not intended as accurate representations of specific fauna, contain idiosyncratic, morphological and behavioral characteristics of animals of various species. In the version of WallCology described here, four distinct simulated species are modeled (Figure 6). At any given time, a dozen or more creatures of various species may be visible in the scene.

Morphology	Behavior	Habitat preference	Population size
	Move along pipes Jittery motion Respond slowly to noise	Prefers cold; indifferent to humidity	Large
		Prefers heat; indifferent to humidity	Large
	Moves along pipes Linear motion, ordinarily slow Responds rapidly to noise	Prefers humid habitat; indifferent to temperature	Medium
	Moves along walls Rapid, non-linear motion Non-responsive to ambient noise	Prefers dry habitat; indifferent to temperature	Small

**Figure 6 Characteristics of WallCology creature populations. Creature images are scaled proportionately.**

The morphological features of the creatures are based on turtles and slugs to give them traits which are identifiable with real living creatures but differences between the real life counter parts make them unique. The two “turtle-like” creatures have six legs and a noticeable tail. Instead of a shell, their back is covered in fur. The size and color of the two make them distinguishable. The two “slug-like” creatures have large eyes and a “tail-like” body. One is covered in white fur while the other has a shell over most of its body.

The locomotion of the creatures is also based on living creatures. The large “turtle-like”

creature wanders around on the background wall of the simulated environment and propels itself by moving its feet as its tail wags. The other three creatures have their movement restricted to the pipes. The smaller “turtle-like” creature slowly glides across the pipe, rarely changing direction. The two slug-like creatures flex/wag their long “tail-like” body quickly across the pipes, often pausing or rapidly changing direction.

Each type of creature also has environmental preferences. The “slug-like” creatures prefer different temperatures and the “turtle-like” creatures are sensitive to humidity. These environmental preferences lead to varying frequencies of visible creatures within the set of WallScopes. For example, the white, furry slug prefers colder temperatures and is rarely seen in a WallScope viewing a hot area of the simulated environment. As creatures move within the larger virtual environment they prefer to stay where they are comfortable and will seek areas that accommodate them.

Although this particular four creature set is well-suited for the learning goals we set forth, they may not be well-suited for others. Addition or change to the WallCology creature set can be done to serve other learning goals. The fall 2007 version of WallCology will decrease the types of creatures to three but emphasize the life-cycles of each. The change is achieved through incorporating new states to the existing client-side code for each creature allowing them to enter egg, pupa, larva and adult stages. Additionally, the fall 2007 version is aimed at teaching food-webs via predation so dynamic population size has been added to the backend server. The server-client messaging has also been added so that the two sides can remain synced.

### **3.3 Interaction affordances**

While designed to support primarily observational science activities, WallCology supports a limited set of user interaction affordances. An indirect affordance is provided by monitoring the ambient volume level obtained through the built-in microphones on the WallScope computers as a marker of human presence. If the noise level is too high, creatures react with species-specific flight responses: some quickly run off-screen, others slowly make their way to the edge of the display, and others simply ignore the human presence.

Styluses attached to the WallScope computers provide two additional interaction affordances. Using built-in Flash capabilities, users can “zoom-in/-out” on the scene by pressing the stylus to the screen and choosing a zoom factor from a drop-down menu. This ability is useful during observational activities when learners are charged with drawing or describing morphological features of small creatures.

A more interesting affordance is the ability to “tag” creatures by using the stylus to “paint” colored dots on the creatures’ torsos. (The tagging capability is used to support population estimation methods that require the tracking of specific creatures over time.) Tagging is accomplished by using the stylus to select a paint color, and then touching the stylus to a selected creature, causing a colored dot to appear and remain on the creature’s torso as it continues to move about the environment. Once tagged, a creature retains the tag indefinitely (unless tagged with a different color).

## 4 ARCHITECTURE & DESIGN

### 4.1 Server Architecture Overview

WallCology is built using a client-server model in which the clients run using Flash Actionscript and the server is written in Java. The server is built on the phenomena server architecture designed by Barron (2006b). This distributed model creates a separation of tasks between the server and the client WallScopes, reducing the computational load on any one computer. On the server-side, the virtual space is decomposed into a collection of containers, each of which represents a physical section of the classroom walls. Each container can be linked with one client to show the contents of that virtual space. Environmental characteristics, as well as information on each creature currently contained within a WallScope, is stored for each container. Each creature is an agent moving between the containers based on environmental preferences. All of WallCology's data is stored in a SQL database modified only by the server. In the event the server or a client is restarted, the current state of the simulation is restored when a connection is reestablished.

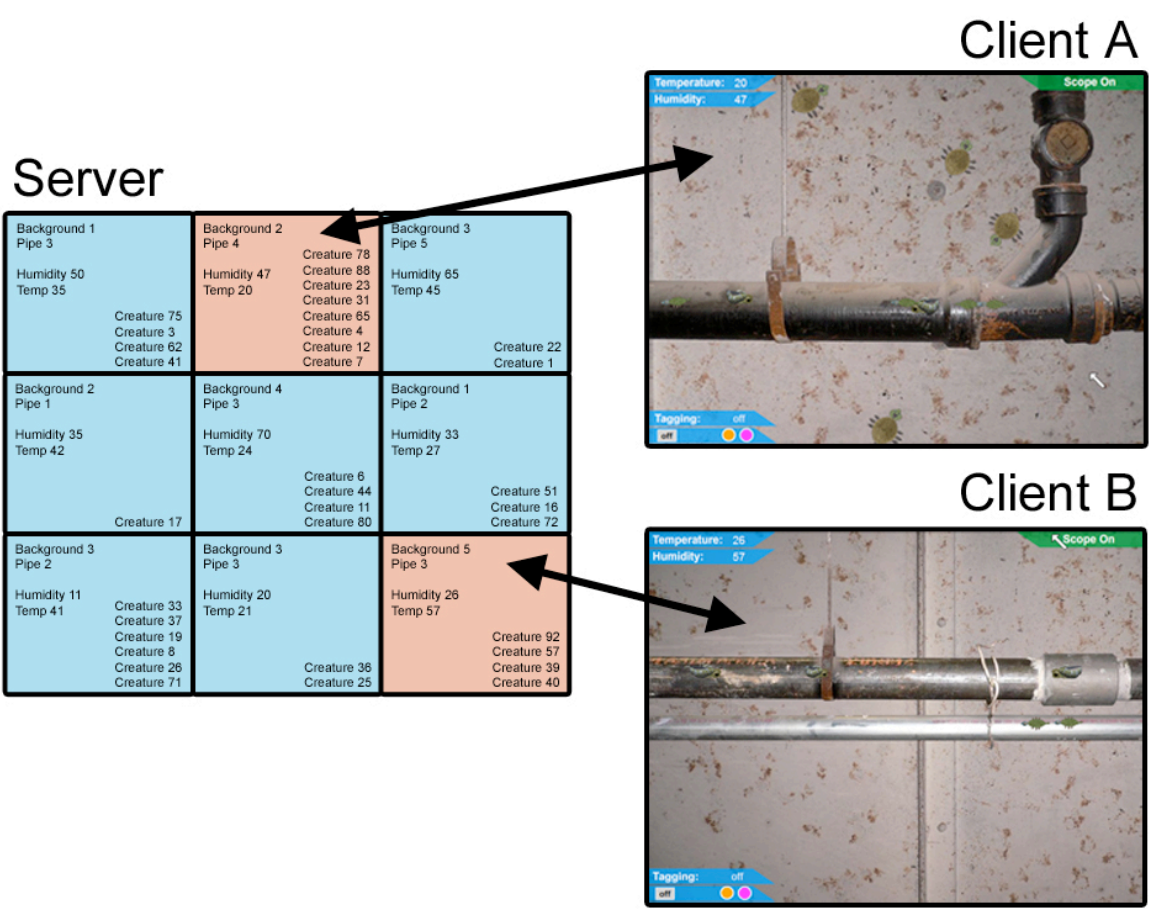


Figure 7 The WallCology 2-tiered approach. The server manages the larger virtual environment and database while clients manage the graphics and user-interface.

**4.2 Client interaction with the Server**

XML is a markup language commonly used to send information over the internet. All of WallCology’s communication between clients and the phenomena server is done via XML messaging. When a client is connected, a socket is connected and kept open to exchange messages between the client and the server. The messaging protocol requires that after a message



is sent (by either the client or the server) a confirmation message must be sent to ensure the fidelity of the representation between the two. Initially, a message is sent identifying the client's location in the physical space of the classroom. Upon receiving this message the server confirms the connection, links the client to a container based on the physical location and then sends a 'populate' message to the client. The 'populate' message contains data for all of the creatures currently in the linked container on the server. All movement between containers (and thus into and out of clients) is controlled on the server-side. When a creature wanders into or out of a container linked to a client, a message is sent from the server to that particular client to update the client's list of creatures to display. The client initializes a message-confirm protocol only when a creature is tagged on the client-side. A tagging message containing the identity of the creature being tagged and the color of the tag is sent to the server and upon confirmation the tag is added to the client creature visualization.

### **4.3 Client Architecture**

#### ***4.3.1 Graphics***

The WallCology Flash document file (*WallCology fla*) holds all graphics and animations used on the client-side. Graphics include overlay graphics, four background wall images, six foreground pipe images and tagger tool graphics. The creature's movement is made possible by four creature animations which cycle through a set of pre-rendered images of creatures modeled in Maya. Animations of tails swishing and legs moving create the illusion of locomotion as the graphics slide across the static wall and pipe images.

### 4.3.2 Control Structure

*WallCology.as* is the central control script which is called directly by the *.fla* graphics file.

This control is done in two parts: a main program loop and message interrupt handling.

The main program loop has essentially four states which are controlled by a set of six functions named *frame1()*, *frame2()*, etc. since they are called in the first, second, etc. frame of the *.fla* file. The function *frame1()* attempts to open a connection with the server. A loop between *frame2()* and *frame3()* waits for the connection to be established. Once the connection is made, *frame4()* initializes the client by creating the environment and the overlay using the graphics and animations in the *.fla* file. The main loop of the WallCology client is between *frame5()* and *frame6()* which check to see if the connection is still live, refreshes the display, surveys microphone levels, and updates the creatures. In the event that the connection is lost the main loop is exited and the program's execution goes back to the "waiting for connection loop." Once the connection is reestablished the client is re-initialized and all graphics are reloaded onto the viewing stage.

Message handling is done by two functions which control the client-side interaction with the server. Incoming messages are handled by a *handleIncoming()* function which interprets the message and then adjusts a global creature array or environmental variables as needed to reflect the state of the server. Alternately a *handleOutgoing()* function creates XML messages to send to the server when at the main loop's request.

Incoming Client Messages	
IN_POPULATE	Contains all creatures in the client's server grid node
IN_ENTER	A creature to be added to the client
IN_LEAVE	A creature to leave a client
IN_ENV	Updated environment variables
IN_TAG	Tag to be added to a creature
Outgoing Client Messages	
OUT_POPULATE	Requests all creatures in the client's server grid node
OUT_RELEASED	Confirms a creature has left the client
OUT_RECEIVED	Confirms a creature has been added to the client
OUT_ADDTAG	Tells the server to add a color tag to a creature
OUT_ENV	Requests environment variables

**Figure 8 WallCology Client Messaging Protocol.**

A global array is used to keep an up-to-date list of all creatures currently located within the WallScope. All addition and deletion to the array occurs in *WallCology.as*. This array is iterated over each time the creatures array is updated so that if any creatures are marked for deletion they are removed from the viewing stage. Also this iteration sends an updates command to each individual creature so that the animation moves forward. Once created, each creature acts as an agent controlling its own behavior until the client receives a message for the creature to leave the scope. This agent-based approach in the client allows each class of creature to control its own behavior without explicit calls from the control script. Creatures need only to be created and eventually told to exit the scope by the control script.

### ***4.3.3 Utility Control Classes***

Flash is based on layers and displays content such that higher layers occlude, and are thus perceived as being in front, of lower layers. A depth manager class, *DepthManager.as*, was created to ensure content is displayed properly. One type of creature moves exclusively on the background wall while the others move about on the pipes. By properly managing all of the

depths, the creatures and backgrounds are properly occluded. Overlay and mouse layers are kept at the top of the hierarchy to ensure that the user interface is visible at all times.

Waypoints are used for pipe-based creature animation. The waypoints are initialized and stored using two *.as* files. The first, *WayPoint.as*, is a class containing member variables and methods which are accessed by creature classes to plot trajectories for their animations. Each waypoint contains a point in the 2D screen space, an array of adjacent waypoints, a type and a thickness. A waypoints type is determined by its location such that if a waypoint is near the edge of the screen it is marked north, south, east or west. If a waypoint is internal and links to waypoints on the edge it is designated as mid. This class also contains a *drawMe()* function which can be used to debug waypoint locations. Waypoint locations, adjacency arrays, types and thicknesses are stored in a script file, *PipeWaypoints.as*, which has four functions containing hard-coded data based on each of the six pipe images. When the environment is initialized by *WallCology.as* the function in *PipeWaypoints.as* corresponding to the pipe image used is called to retrieve the proper waypoint locations which are stored in a global array of *WayPoints*.

#### **4.3.4 Creature Class Hierarchy**

WallCology contains four types of creatures but the need to add others or modify the current creatures is likely to arise in future iterations. Thus, a creature class hierarchy is used to promote code reuse. The root creature class, *Creature*, has two subclasses *WallCreature* and *PipeCreature* which separate the types of creatures by location since movement on the pipes is restricted to a small area unlike movement on the background wall. There is one subclass of *WallCreature*, *WallTurtle*, which is the only wall bound creature. WallCology has three types of

pipe-bound creatures which inherit class members and methods from *PipeCreature*. *PipeTurtle* is a base class and *Bug* is sub-classed into *BugHot* and *BugCold*.

*Creature.as*, contains member variables and methods which are necessary for controlling each creature. Many of the methods in *Creature.as* are intended to be overwritten but provide the coder with a primer of necessary methods. Thus *Creature* is implemented with basic functions to govern simple movement but is not directly usable since there is no animation corresponding to the class. Creature name, age, tag color, and animation depth are the data needed to construct a new creature. Name, age and tag color are received through messaging from the server's SQL database and animation depth is set by the global depth manager in the *WallCology.as* script. Each subclass of *Creature* defines a set of animation strings based on the age and desired look of the creature. *Creature* uses this string to assign the proper animation to the object. Some basic utility functions, *SetStartCoordinates()* and *BoundInWindow()*, are also implemented here for use in subclasses.

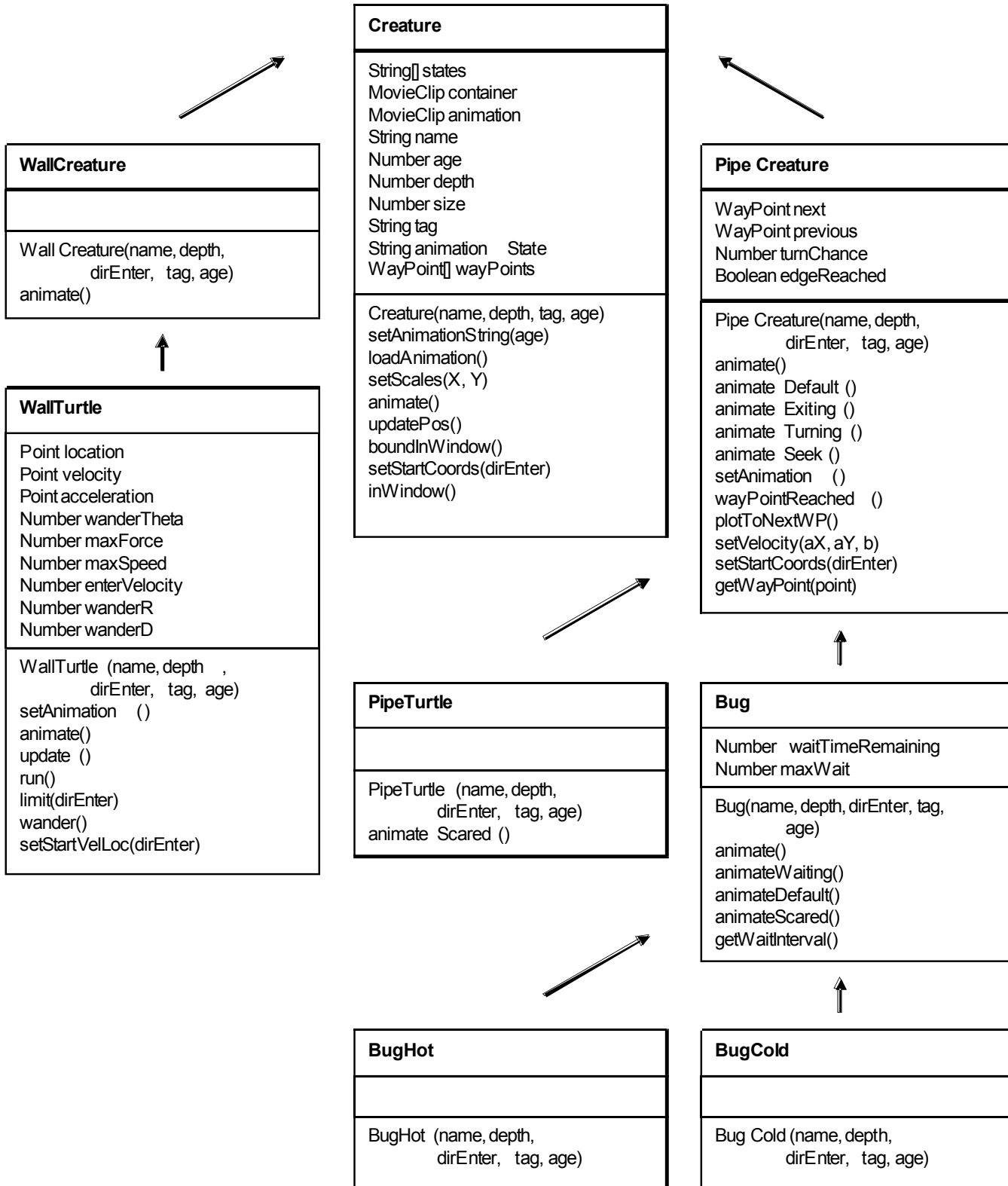


Figure 9 UML class diagram of the Creature hierarchy.

#### 4.3.5 State-Based Animation

The animation of the creatures is state-based which allows for strict control of the behavior and look of each creature. Three basic states are needed: *default*, *exiting*, and *exited*. The *default* state plays the creature's basic locomotion animation and maintains that the creature stays in the bounds of the WallScope. When the server requests that a creature exit a scope the creature's state is set to *exiting* by the *WallCology.as* control script. This state moves the creature to the edge of the WallScope where after it leaves the scope it enters the *exited* state which marks the creature object for deletion. The control script then pops the creature from the array and a confirmation message is sent to the server. The only *WallCreature*, *WallTurtle* has no additional states since its movement is a random wander seen often in boid behaviors originally implemented by Reynolds (1987).

All *PipeCreatures* have the additional states *turning*, *seek* and *scared* which break out of the *default* state. The *seek* and *turning* states manage the waypoint guided movement of the *PipeCreatures* and the *scared* state is used to change the behavior of the creatures which are responsive to classroom sound levels. The *turning* state is triggered when a creature reaches a goal waypoint and needs to find a new waypoint to move towards. Since the *turning* state alone would cause creatures to only change direction when they reach a waypoint the *seek* state was added to randomly change the creature's direction between waypoints. Creatures' responses to classroom noises vary and are controlled in the *scared* state. When frightened, *Bugs* move slowly and turn transparent whereas the *PipeTurtles* run quickly off screen. The *Bug* subclass of

*PipeCreature* adds yet another state, *waiting*, which is used to add a random pause in movement as the creature moves along the pipes.

As more behaviors (e.g. eating, sleeping, etc...) are needed the state-based animation schema will allow for easy addition of the necessary control. Movie clips within Flash document files can be used to show these different behaviors and code controlling the change in movement can be added by inserting an additional state.



## **5 PILOT STUDY**

### **5.1 Subjects**

The spring 2007 pilot study of WallCology was conducted in an urban 7<sup>th</sup> grade classroom. The class consisted of 31 students, primarily Latino (52%) and African-American (32%). The class consisted of 14 girls and 17 boys, including one English Language Learner (English as a second language) and two special education students.

The students remained in the room with the phenomena as their teachers switched classrooms to teach subjects to other sets of students. WallCology ran for the duration of the eight-week study and the students had access to it whenever they were in their classroom (over five hours a day). Science was taught in this classroom 3-5 days a week for periods ranging from 40-90 minutes. This pilot study was conducted in April, 2007.

The class of 31 students was divided into 5 workgroups by the teacher. Each group of students was assigned a WallScope but also allowed to roam to other WallScopes to collect data and discuss findings with other workgroups.

### **5.2 Instruction Method**

In the pilot study, WallCology was used as a component of an eight-week population ecology unit. The unit also included supplemental activities which were selected to provide learners with needed concept knowledge to carry out their work as WallCology investigators. The eight weeks were broken into two sub-units focusing on the learning goals of species differentiation and

mobile population estimation. The students worked in five small groups, one per WallScope in the classroom.

The species differentiation unit preceded the population estimation unit because sub-grouping the creatures was required to properly sample the population. The class collaboratively decided how they would group the creatures in the species differentiation activities so that when calculating the population size they could use this grouping to gather more meaningful data. Without the classification, students could have estimated the total number of creatures in the walls but not the individual population sizes of each sub-group. Ecologists first sub-group or classify the creatures being studied before a proper estimate the population size can be formed when studying a new ecosystem.

### ***5.2.1 Species Differentiation***

The students were first acquainted with the simulation via a class discussion designed to provide them with an introduction to the simulation, focus them on goals, encourage them to take ownership, and to answer any questions they may have. The students were introduced to the system by telling them that scientists had discovered a previously unknown ecosystem within the walls of their classroom. The ecosystem has existed there all along, but the technology allowing us to see into the walls with minimal disruption to the environment has recently been developed. Since these scientists are very busy working on other projects, the learners were told that it was up to them to conduct research and form conclusions about the creatures and their habitat.

The class's first goal was to differentiate and group the creatures. The creatures were to be sub-grouped such that each sub-group had a set of unifying characteristics shared by every member of the proposed group. Scientists use a hierarchical classification to group living organisms. Life is divided into domains. Domains are divided into kingdoms. Kingdoms are divided into phylum then class; order; family; genus; species, and sometimes sub-species. As more data is acquired and more research is conducted, these classifications are continually redefined. Even the highest classification of life in general is sometimes disputed but there are characteristics which are commonly used to group living organisms at the various levels of the hierarchy. Ecologists use a creature's morphology, behavior, environment and anatomy to perform classification. WallCology is designed to allow for the study of creatures as ecologists would in the field. Ecologists in the field seek to unobtrusively observe their specimens and thus they do not have access to internal anatomy. Therefore field ecologists and WallCology students focus on the former three aspects.

Two classification exercises preceded the WallCology creature differentiation activities. The first required that students remove their shoes and create a dichotomous key of the entire classroom's shoes. Dichotomous keys classify groups into sub-groups by creating mutually exclusive groups. By starting first with a small number of shoes and then moving to incorporate the entire room, the students were led to consider what factors were well-suited for classification. A similar activity was then conducted in which the class categorized paper clips of different size, shape, and color.

The WallCology species differentiation activity focused the four types of creatures which were employed in the simulation. In order to problematize species differentiation and encourage learners to consider characteristics beyond morphological features, each of two pairs of creatures was assigned similar (but not identical) morphologies, but with distinct behavioral patterns and habitat preferences (Figure 6). The objective was not to lead students to a normative determination of species membership, but rather to use observational activities as a stimulus for theory articulation and argumentation (Smith & Reiser, 2005). Students worked in their small groups to create a “field guide” of WallCology creatures (Figure 10). Each page of the field guide asked students to sketch the creature and provide their observations of the creature’s morphologies, behaviors, and habitats. After a few days of observation, each group decided upon both a common name for each creature as well as a scientific name using Latin and/or Greek root words to promote ownership of the data. Once the field guides were completed by each workgroup, the teacher led whole-class discussions designed to reach a class consensus regarding the identification of distinct species.


<p>Morphology Sketch</p> 	<p><b>Species:</b>          (Latin/Greek) <u>Chloro</u>          (meaning) <u>green</u>          (common) _____</p>
	<p><b>Morphology:</b>          (written description) <u>I has a green body and a greenish blue head. It has six legs. It has a diamond shaped head</u></p>
	<p><b>Behavior:</b>          (normal activity) <u>I move slow until here a loud clap or any type of noise.</u>          (frightened) <u>It moves very fast when it hears noise or when it feels intimidated</u></p>
	<p><b>Environment:</b>          (habitat) <u>It lives in a dark area in the walls. It likes to be on the rusty pipes. It hangs around its own kind.</u>  <u>High humidity</u></p>

Figure 10 WallCology Field Guide Page.

### 5.2.2 Population Estimation

In conjunction with the population estimation activity, two mathematical sampling exercises were first performed by the class. In the first activity the students estimated the number and composition of students in specific areas of their school based on sample data they collected. They were first asked to estimate class size using only one of their small groups and knowledge

that there were five groups. Eventually the activity led to a discussion on the best means of determining the size and composition of their entire school using sampling of multiple classrooms in multiple grades.

Attention turned next to obtaining estimates of creature population sizes across the entire WallCology (visible and hidden) environment. Population estimation focused on two techniques: static sampling, which is similar to the school population activity, and mark-recapture estimation consistent with the Lincoln-Peterson (Pollock, 2000) method. Students first estimated WallCology populations using the static sampling method. For 5 minutes at a time, students observed the screens and noted how many creatures of each kind that they saw. They then multiplied this quantity by the number of WallScopes that would fit on their wall according to their measurements. A classroom population estimate was then reached by adding the estimates for each wall. The process was repeated several times in conjunction with a class discussion on reliability, accuracy, and factors that could lead to inconsistent results.

Before performing the mark-recapture method on the creatures of WallCology, the class preformed the method on a large container filled with a variety of beans. Each group grabbed, counted, and marked a handful of beans from the container. All beans were then returned to the container so that the marked and unmarked beans were mixed. Students then grabbed another handful to count. While conducting the activity, students were instructed on the mark-recapture method and the mathematics behind it.

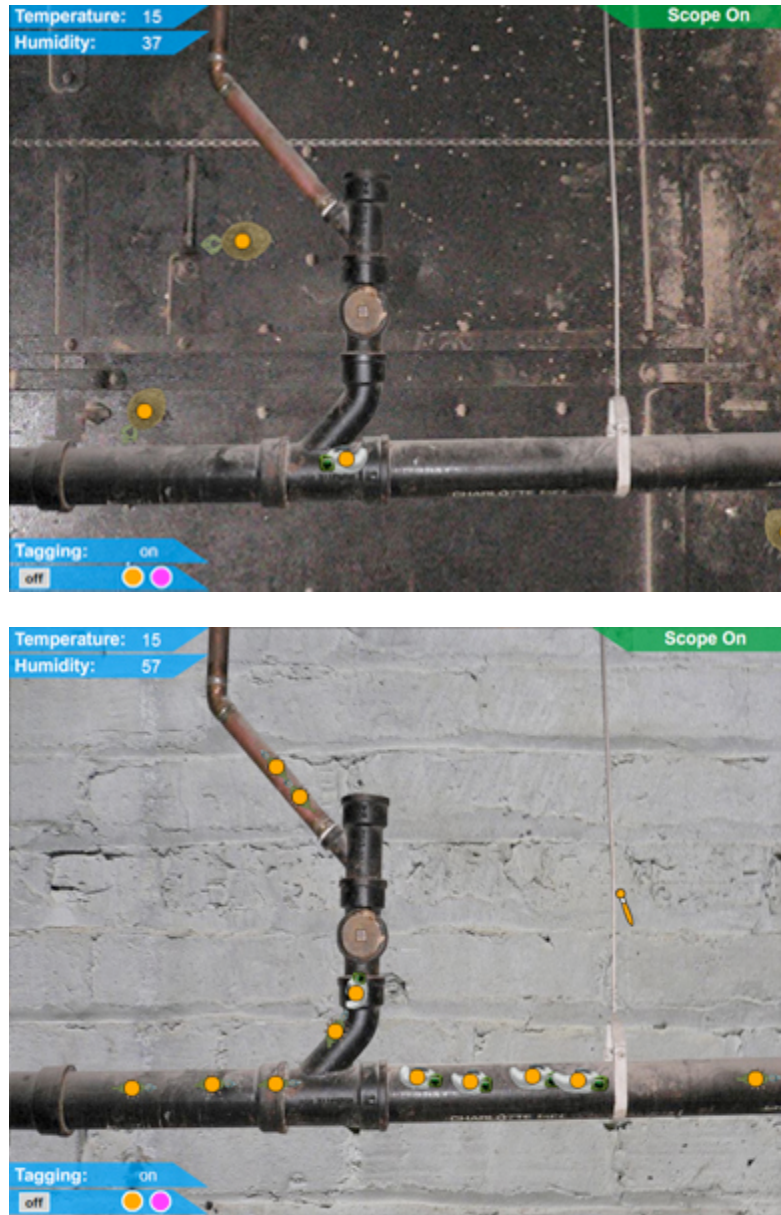


Figure 11 Tagged creatures in WallCology Habitats.

The Lincoln-Peterson (Pollock, 2000) method of mark and recapture is derived from mathematical probability. The estimated population size is:  $N = \frac{n_1 n_2}{m}$ , where  $n_1$  is the

number of creatures captured in the first session,  $n_2$  is the number of creatures captured on the second session and  $m$  is the number of previously marked creatures captured in the second session. The formula follows from the observation that if  $n_1$  is defined as a population then the probability of capturing a marked creature from the  $n_1$  population during another session is  $m/n_1$ . The probability of capture in the larger population can be written as  $n_2/N$ . Through assuming that the population being studied is closed (i.e. no birth, death, immigration or lost tags) and since  $n_1$  is a subset of  $N$ , the equation  $n_2/N = m/n_1$  is valid. Rearrangement of this equation yields: 
$$N = \frac{n_1 n_2}{m} .$$

Since WallCology offers samples of a closed but mobile population the mark-recapture method is well-suited to perform population estimation. Using the built in tagging facility of the WallScopes, students marked and counted every creature that wandered into their WallScope over a thirty-minute class. On the next day the procedure was repeated using a new color. Students again recorded how many creatures were captured. Additionally they recorded how many of these creatures were previously marked. As in the static sampling exercise, a discussion of how to improve sampling accuracy of the mark-recapture method by sampling at various times and places concluded the activity.



## **5.3 Data Sources**

### ***5.3.1 Pre/Post-tests***

Identical tests on species differentiation and mobile population estimation were administered to the students before and after the eight-week WallCology unit. These tests included open-ended items to probe understanding and were used to assess/compare prior knowledge against current knowledge. Additionally, selected Likert-scale items from the Test of Science-Related Attitudes (TOSRA) (Fraser, 1978) were used to assess changes in the students overarching attitudes toward science.

### ***5.3.2 Field Guides, Journals, & Classroom Video***

The individuals in each student group worked collaboratively to complete field guides and individually wrote in science journals. Descriptions of observed morphology, behavior, and habitat preference, along with population estimation information, were collected for analysis. Five hours of video containing small-group and whole-class discussion was also recorded on selected days during the WallCology unit.

### ***5.3.3 Post Interviews***

Nine students and the teacher were interviewed individually. A group classroom discussion to gather additional feedback on the unit was also recorded. These post interviews were directed at overall understanding of the content and student attitudes toward WallCology, including the issue of simulation realism.

## **5.4 Results and Findings**

### ***5.4.1 Species Differentiation***

Early classroom discussions showed the students initially focused on morphology as a means of species differentiation. Attention to behavior and environmental preferences of the individual creatures was used as secondary evidence. This tendency was supported by the written observations in the field guides and science journals. The morphological descriptions of the creatures were detailed and accompanied by student sketches of the creatures. (e.g. “It has a green body and a greenish blue head. It has six legs. It has a diamond shaped head.”) The behaviors section cited less detailed observations. The physical actions noted were often accompanied by student explanations of why creatures were behaving in the observed way (e.g., “It is scared of the turtle-like thing and that’s (why) we think it never comes out (of) the pipes”). The environmental observations were largely focused on the physical characteristics of the pipes and walls.

The use of the field guides and science journals as reference materials in classroom discussions demonstrated that students were able to use their collected data as evidence for conclusions and theories. The peer review discussion at the conclusion of the species differentiation sub-unit was aimed at answering the question, “How many species of creatures are there in WallCology?” Initially students cited morphology to make claims like “the two sleach (combining slug and leach) creatures are the same species because they look alike” and “the small turtle and big turtle creatures might be the same species but the small one could be a baby living on the pipes.” One group then stated agreement with the single sleach theory and

added that they have the same behavior, citing recordings in their field guide. The same group stated that the turtle-like creatures had differing behaviors but that perhaps the turtles do not get scared when they are fully grown. The peer review exercise concluded with the drawing of a chart showing similarities and differences among the morphologies, behaviors and environments of the creatures. Collectively, the students concluded that there were four different types of creatures (sub-species) but that two of the types were from the same species. Thus they concluded there are three different species in WallCology.

Post-unit interviews indicated that the students used morphological, behavioral, and environmental traits as evidence for species classification. The following are examples of student responses to the question, “If you have two creatures, how did you tell if they were the same species?”

*“I would look at the way they looked and how they reacted to different things. So if you scare them, how they reacted.”*

*“You have to go over morphology, how they look, and the way they behave when you are around them and their environment...where they stayed was it humid or cooler.”*

*“By looking at their body...where they’re from, their habitat, and their environment.”*

*“Because they would look the same only be a different color or different attitude... The ones that looked like slugs one was white and one was grey, one would go faster and one would go slower but then they both would both go invisible because they got scared.”*

Unfortunately, pre- and post-test scores on a species differentiation item exhibited a ceiling affect (Appendix A). Two open-ended questions were designed to assess students understanding that morphology, behavior and environment offer clues for species differentiation. The questions

presented students with two photos, each of a different creature, as well as a short paragraph discussing behaviors and environment and asked them to discuss why two creatures might or might not be members of the same species. In the pre-test, students properly discussed all three factors and offered arguments for and/or against the two creatures being from the same species. The post-test answers exhibited similar discussions revealing little change. In future studies the assessment should be rewritten to provide contrast between pre and post-test scores. Presenting morphological, behavioral, and environmental data in a format where it must be extracted by the student instead of offering the data directly may elicit more meaningful data. For example, showing a short video clip, without narration, of individual creatures in their natural environment presents data but does not explicitly give it.

#### ***5.4.2 Population Estimation***

Pre/post-tests provided evidence of increased understanding of population estimation methods. For the assessments, students were asked to name and describe two methods of performing population estimation. Pre-test answers predominantly fell into the following categories: a) don't know or blank, b) discussion of a way to simplify the task of counting every individual (grouping) but omission of extrapolating to reach an estimate, or c) discussion of other invalid means of estimation. Post-tests showed improvement in the students' descriptions of the two population estimation methods. Most students correctly described a form of static sampling or defined a similar valid method of population estimation. Over half of the students named and discussed mark and recapture as their second method. A few students discussed the Lincoln-

Petersen formula for mark-recapture and/or gave a highly detailed explanation of how to conduct the mark-recapture method.

The post-interviews of students included the question “How would you figure out the population size of a species? What method would you use?” Of the nine students interviewed, seven named the mark-recapture method (or as some called it “the tagging method”) as the method they would use. Six of these students stated that they would count/mark the creatures and then average the amounts together. Three students accurately described the Lincoln-Petersen formula.

In the post-interviews, students were also asked “What was your favorite part of WallCology?” Eight of the nine students stated “tagging” was their favorite part. When asked why “tagging” was their favorite part, common answers included: “because we got to touch the creatures,” “it was like a video game,” and “it was fun...and hard because they were fast.”

#### ***5.4.3 Science Attitudes***

A paired t-test analysis of the TOSRA pre/post-tests showed 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.” The analysis also showed 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.”

The individual interviews and group discussion indicated that many of the students' were increasingly interested in ecology science. Detailed ecology questions were commonly asked toward the end of the unit. Many students also expressed interest in repeating their experiments to gather new data that would confirm or lead to revision of their initial results.

## **5.5 Discussion**

Students were actively engaged in the species differentiation activity for the first two to three days as they described and recorded the first one or two creature types. As the workgroups moved on to describe the final creature types, attention dropped off sharply. In each group's field guide the descriptions of the first two species were the most detailed and the following descriptions were vague with omitted sections. Students likely felt that they understood the species differentiation concepts after defining the first two species and found that repeating the exercise on the following creatures was not challenging. After observing for a few days some students indicated that they felt that there was nothing new to observe and that recording the data had become a chore.

The engaging factor of "having something new to study" could be prolonged in the species differentiation unit by not introducing the students to all of the creatures at one time. This could be achieved by adding new creatures after the first few have been studied or by making the distribution of animals less homogeneous (so that, for example, only one or two types of creatures at a time are visible on a given WallScope). The teacher could then control when work groups are exposed to the creatures by moving them from one WallScope to the next or by allowing students to choose where to observe the environment.

The mark-and-recount population estimation activity was, for many students, the highlight of the entire WallCology experience. In discussions, most students cited tagging the creatures as being the “most fun part” of WallCology. This strong level of engagement likely contributed to the students understanding of the underlying method, which is one of the more difficult concepts posed to the students during the unit. Equal time was spent studying the static sampling method and the mark-recapture method, but students in post-unit interviews discussed the mark-capture method in much more detail than the static sampling method.

Aside from providing affordances for teaching ecological goals, WallCology seeks to improve participant’s overall attitude toward science. The TOSRA questions, in-class discussions and individual interviews reflect a positive change in science attitudes in the pilot class. A positive attitude toward an activity is often improves student performance since it causes spontaneous rather than conscious attention toward the activity (Hidi, 1990).

The TOSRA questions and the post-interviews also indicated an increased agency by students in conducting their own investigations. The desire to conduct experiments rather than have the answers given to them by a teacher and to repeat these experiments shows that student perceive themselves as investigators. This is important because as students become adults it is important for them to be capable of making informed decisions based on evidence on their own without use of an external authority.

Interestingly, a substantial segment of the class believed, at least on some level, that the simulation was real. The designers and educators involved in WallCology did not seek to create an environment in which the students believed that the simulation was reality, but the fact that

WallCology is a simulation was never explicitly stated until the final discussion. The students were told at the beginning of instruction that they would be studying a new ecosystem found in the walls of their classroom, leaving them free to draw their own conclusions. Many students stated that they had serious doubts that led them to believe that WallCology was just a simulation at the beginning of instruction but that they set those doubts aside. On more than one occasion students tested WallCology's realism by banging on walls away from WallScopes to see if there were reactions within the scope. Students were also asked during the group discussion if the realism of the simulation was a factor in their learning and interest in WallCology. Several students quickly volunteered that believing the simulation to be real on some level had a significant motivational effect. They enjoyed being the first group to work on this newly discovered ecosystem and were motivated to do their best to understand it.



## 6 CONCLUSION

This thesis described the WallCology learning technology, designed to support student understanding of population ecology concepts. The educational motivation of this system is to provide affordances for science inquiry learning based on content standards set by the AAAS and NRC. Additionally WallCology seeks to deliver these affordances in a manner consistent with the current views of science educators. The system provides classroom access to a virtual environment within a framework that promotes active science learning and cooperation amongst learners while participating in small workgroups or in full-class activities.

WallCology's contribution to computer science is two fold: 1) it is a unique ubiquitous computing technology and 2) it provides extensions to the Embedded Phenomena framework. WallCology has been placed in the context of emerging ubiquitous and tangible learning technologies by the discussion in this thesis. The system provides access to the virtual environment at the periphery of a classroom and at any time a user's focus can be shifted easily from one location to another, bringing a single WallScope to the center of attention. The implementation of WallCology is unique amongst other Embedded Phenomena in that it was designed as a platform for the inclusion of many ecology learning goals. Also, a two-tiered approach to implementation was used to divide client-side interface and graphics from the larger virtual environment. This creates the potential to view the simulation at multiple sites mapped to a single or multiple rooms. This opportunity for cross-classroom collaboration has previously not existed within the embedded phenomena framework.

The pilot study in an urban middle school classroom gave support for tentative claims that WallCology can be effective in supporting learners' development toward the understanding of population ecology concepts. The species differentiation and population estimation activities were successful in presenting some of the issues ecologists encounter in the field. Students showed a high level of engagement and interest in the “tagging” exercises and also discussed population sampling techniques in post-tests with which they were previously unfamiliar. Post interviews and pre/post-test comparisons of science attitudes revealed an increased agency amongst participants.

Future studies should focus on testing WallCology's extensions to the Embedded Phenomena framework as well as the inclusion of features that further promote learning of ecological principles. Placing WallCology in two or more classrooms with an adjoining virtual space will test cross-classroom collaboration within the altered framework. The eventual incorporation of mobile devices will allow learners to choose when and where to observe the phenomena as well as increase access to more areas of the virtual environment. Additional interface instruments like the “tagger” should further increase student engagement. Increasing the complexity of the environment and introducing new creatures will create opportunities for teaching new learning goals. Adding environmental attributes and introducing more variation within the virtual space will provide an intricate base for new creatures with more advanced interactions. All of these factors will change and hopefully extend the use of WallCology as a learning technology.

WallCology has been designed with expansion beyond this first iteration in mind and many of these expanding features are not far from completion. The grander vision that I have is that

one day the WallCology system provide a complex, simulated ecosystem that is used by numerous classrooms on multiple grade levels as a long-term supplement to an inquiry-based ecology curriculum.

## 7 CITED LITERATURE

- American Association for the Advancement of Science: Benchmarks for Scientific Literacy New York: Oxford University Press, 1993.  
<http://www.project2061.org/publications/bsl/online/bolintro.htm>
- Azuma, R.: A Survey of Augmented Reality. Presence: Teleoperators and Virtual Environments 6(4): 355-385, 1997.
- Azuma, R. Baillot, Y. Behringer, R. Feiner, S. Julier, S. Macintyre, B.: Recent Advances in Augmented Reality. IEEE computer graphics and applications 21, 6, 34-47, 2001.
- Barron, M., Moher, T., Maharry, J.: RoomBugs: Simulating Insect Infestations in Elementary Classrooms. SIGCHI Conference on Human Factors in Computing Systems, 315-320, 2006a.
- Barron, M.: A System for Embedding Phenomenon in the Classroom: The RoomBugs Architecture and Experience. University of Illinois at Chicago, M.S. Thesis, 2006b.
- Benford, S., Rowland, D., Flintham, M., Hull, R., Reid, J. et al.: Savannah: Designing A Location-Based Game Simulating Lion Behavior. International Conference on Advances in Computer Entertainment Technology, ACE, 2004.
- Colella, V.: Participatory Simulations: Building Collaborative Understanding Through Immersive Dynamic Modeling. Journal of the Learning Sciences 9:471-500, 2000.
- EQUATOR Project. 2007. <http://www.equator.ac.uk/>
- Fraser, B.: Development of a Test of Science-Related Attitudes. Science Education, 62(4), 509-515, 1978.
- Hidi, S.: Interest and Its Contribution as a Mental Resource for Learning. Review of Educational Research, Toward a Unified Approach to Learning as a Multisource Phenomenon (60)4, 549-571, 1990.
- Johnson, R., and Johnson, D.: Action research: Cooperative learning in the science classroom. Science and Children, 24, 31-32, 1986.
- Johnson, D., and Johnson, R.: Leading the cooperative school. Interaction Book Co., MN, 1994.
- Klopfer, E., Squire, K., Jenkins, H.: Environmental Detectives: PDAs as a Window into a Virtual Simulated World. Proc. Wireless and Mobile Technologies in Education, 95-98, 2002.

- Milgram, P. and Kishino, F.: A Taxonomy of Mixed Reality Visual Displays. IEICE Transactions on Information Systems 12, 1321-1329, 1994a.
- Milgram, P., Takemura, H., Utsumi, A., Kishino, F.: Augmented Reality: A Class of Displays on the Reality-Virtuality Continuum. SPIE Proceedings: Telem manipulator and Telepresence Technologies. SPIE. 2351, 282-292 1994b.
- Moher, T.: Embedded Phenomena: Supporting Science Learning with Classroom-sized Distributed Simulations. SIGCHI Conference on Human Factors in Computing Systems, 691-700, 2006.
- NetLogo. Center for Connected Learning and Computer-Based Modeling, Northwestern University, IL, 2007. <http://ccl.northwestern.edu/netlogo/>
- National Research Council: National Science Education Standards. Washington, DC: National Academy Press, 1996. <http://newton.nap.edu/html/nses/>
- Pollock, K.: Capture-Recapture Models. Journal of the American Statistical Association, 95(449) 293-296, 2000.
- Price, S., Rogers, Y., Scaife, M., Stanton, D., Neale, H.: Using 'Tangibles' To Promote Novel Forms Of Playful Learning. Interacting with Computers 15, 169-185, 2003.
- Randell, C., Phelps, T., Rogers, Y.: Ambient Wood: Demonstration of a digitally enhanced field trip for schoolchildren. Adjunct Proc. IEEE UbiComp, 100-104, 2003.
- Resnick, M.: StarLogo: An Environment for Decentralized Modeling and Decentralized Thinking. SIGCHI Conference on Human Factors in Computing Systems, 11-12, 1996.
- Reynolds, C.: Flocks, Herds, and Schools: A Distributed Behavioral Model, in Computer Graphics, Proc. SIGGRAPH Conference, 25-34, 1987.
- Riel, M.: Cross-classroom collaboration in global learning circles. In The Cultures of Computing, Susan Leigh Star, (Ed), Oxford: Blackwell Publishers/The Sociological Review Monograph Series, 219-242, 1995.
- Rogers, Y.; Price, S.; Harris, E.; Phelps, T.; Underwood, M. et al.: Learning Through Digitally-Augmented Physical Experiences: Reflections on the Ambient Wood Project, 2002. <http://www.equator.ac.uk/papers/Ps/2002-rogers-1.pdf>
- Slavin, R.: Cooperative learning: Theory, research, and practice. Boston, MA, Allyn & Bacon, 1995.

- Smith, B., and Reiser, B.: Explaining Behavior Through Observational Investigation and Theory Articulation. Journal of the Learning Sciences, 14(3), 315-360, 2005.
- StarLogo. Massachusetts Institute of Technology Media Lab. Cambridge, MA, 2007a.  
<http://education.mit.edu/starlogo/>
- StarLogo Models Library. Massachusetts Institute of Technology Media Lab. Cambridge, MA 2007b. <http://education.mit.edu/starlogo/models/>
- STELLA. iSee Systems. Lebanon, NH, 2007.  
<http://www.iseesystems.com/software/education/StellaSoftware.aspx>
- Vygotsky, L.: Mind in Society. Harvard University Press, Cambridge, MA, 1978.
- Weiser, M.: Some Computer Science Problems in Ubiquitous Computing (reprinted as Ubiquitous Computing). SIGMOBILE Mobile Computing and Communications Review, 137-143, 1999.
- Weiser, M.: The world is not a desktop. Interactions, 7-8, 1994.
- Wilensky, U.: NetLogo Bug Hunt Camouflage model. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL 2005.  
<http://ccl.northwestern.edu/netlogo/models/BugHuntCamouflage>
- Woods, E. Billingham, M. Looser, J. Aldridge, G. Brown, D. Garrie, B. Nelles, C.: Augmenting the Science Centre and Museum Experience, Proceedings of the 2nd international conference on Computer graphics and interactive techniques in Australasia and South East Asia, ACM Press, New York, 230-236, 2004.

## **APPENDICES**

## APPENDIX A: Species Differentiation Assessment

Name \_\_\_\_\_

Multiple Choice: (**Circle 1 of the answers** for each of the following questions)

1. Which of the following characteristics are used to classify creatures into groups?
  - a. morphology (the way creatures look)
  - b. behavior (the way creatures act)
  - c. environment (the places creatures live)
  - d. all of the above
  
2. Which of these statements about studying creatures in their natural environment is true?
  - a. It is important to be quiet and careful to not disturb the creatures.
  - b. Creatures do not react to observers.
  - c. The only way to study creatures is to take them out of their natural environment.
  - d. none of the above
  
3. Which of these is true of field guides about living organisms?
  - a. They are used by scientists to understand creatures and the environment.
  - b. They contain information that can be used to differentiate one species from another.
  - c. They can be used by anyone interested in science
  - d. all of the above







## APPENDIX B: Student Interview Questions

### Part I: Species Differentiation and Population Estimation

\*\*\*\*\*

#### **How could you tell if two creatures were the same species?**

*Assessing use of morphology, behavior, and environment as queues.*

#### **How sure were you about your species classification? Why?**

*Assessing students understanding that future research could yield different classifications.*

#### **How would you figure out the population of a species? What were the methods you used?**

*Assessing knowledge of sampling methods. (static and tagging)*

#### **How did you use the field guide?**

*General inquiry.*

#### **Were there differences between what your group found and the other groups found? How do you know? How would you resolve differences?**

*Assessing collaboration and result discrepancies.*

### Part II: Science Attitudes and Realism

\*\*\*\*\*

#### **What would happen if we put a hole in one of the walls of your classroom, what would you see?**

*Understanding simulation representation.*

#### **Some students think the opposite. What would you say to them?**

*Follow up to first question.*

#### **What was your role in WallCology? Did you do science research? So would you say you were a scientist?**

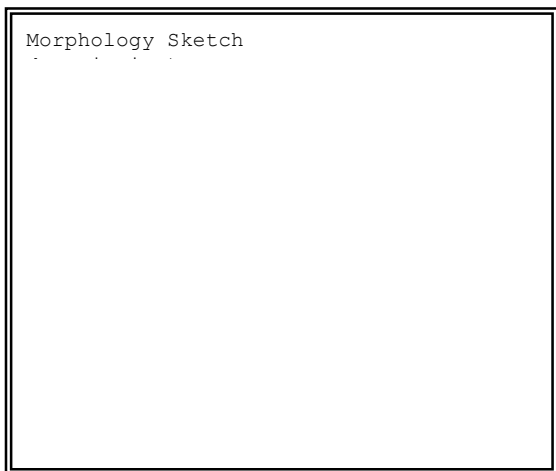
*Understanding how students felt when working with WallCology.*

#### **Talk to me about this activity as compared to other science activities.**

*Overall attitude toward WallCology as compared to other science learning the student has participated in*

**APPENDIX C: Field Guide**

Morphology Sketch



**Species:**

(Latin/Greek) \_\_\_\_\_

(meaning) \_\_\_\_\_

(common) \_\_\_\_\_

**Morphology:**

(written description) \_\_\_\_\_

\_\_\_\_\_  
\_\_\_\_\_  
\_\_\_\_\_

**Behavior:**

(normal activity) \_\_\_\_\_

\_\_\_\_\_

(frightened) \_\_\_\_\_

\_\_\_\_\_

**Environment:**

(habitat) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**Population Size:**

(timed sample results) \_\_\_\_\_

\_\_\_\_\_

(mark and recapture results) \_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

\_\_\_\_\_

**APPENDIX D: Field Guide (Continued)**

## Species Count Sheet

Screen: \_\_\_\_\_ Time: \_\_\_\_\_



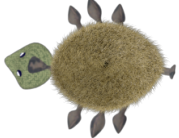

Environment Temperature: \_\_\_\_\_



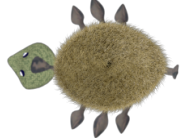

Environment Humidity: \_\_\_\_\_

Screen: \_\_\_\_\_ Time: \_\_\_\_\_

Environment Temperature: \_\_\_\_\_

Environment Humidity: \_\_\_\_\_

Type of Creature	Population
	
	
	
	

Type of Creature	Population
	
	
	
	

Screen: \_\_\_\_\_ Time: \_\_\_\_\_



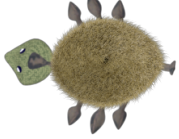

Environment Temperature: \_\_\_\_\_



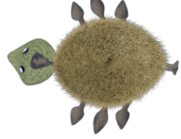

Environment Humidity: \_\_\_\_\_

Screen: \_\_\_\_\_ Time: \_\_\_\_\_

Environment Temperature: \_\_\_\_\_

Environment Humidity: \_\_\_\_\_

Type of Creature	Population
	
	
	
	

Type of Creature	Population
	
	
	
	

## VITA

NAME: Brian Eric Uphoff

EDUCATION: B.S., Mathematics and Computer Science, University of Illinois, Urbana-Champaign, Illinois, 2005

WORK EXPERIENCE: National Science Foundation Scientists, Kids and Teachers Program (SKIT) Graduate Fellow, University of Illinois at Chicago, Chicago, Illinois, 2006-2007

Project Coordinator & Video Editor, Children's Math Worlds Project, Houghton-Mifflin Publishing and Northwestern University, Champaign, Illinois 2003-2005

PUBLICATIONS: Uphoff, B., Bhatt, D., Moher, T., et al.: WallCology: Studying Ecology using a Distributed, Persistent Virtual Ecosystem in the Classroom. *Submitted for Publication, American Educational Research Association*, 2008.

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.