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EMPLOYING INQUIRY-BASED COMPUTER SIMULATIONS AND EMBEDDED SCIENTIST VIDEOS TO TEACH CHALLENGING CLIMATE CHANGE AND NATURE OF SCIENCE CONCEPTS

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ABSTRACT OF THE DISSERTATION

Design based research was utilized to investigate how students use a greenhouse effect simulation in order to derive best learning practices. During this process, students recognized the authentic scientific process involving computer simulations. The simulation used is embedded within an inquiry-based technology-mediated science curriculum known as Web-based Inquiry Science Environment (WISE). For this research, students from a suburban, diverse, middle school setting use the simulations as part of a two week-long class unit on climate change. A pilot study was conducted during phase one of the research that informed phase two, which encompasses the dissertation. During the pilot study, as students worked through the simulation, evidence of shifts in student motivation, understanding of science content, and ideas about the nature of science became present using a combination of student interviews, focus groups, and students' conversations. Outcomes of the pilot study included improvements to the pedagogical approach. Allowing students to do "Extreme Testing" (e.g., making the world as hot or cold as possible) and increasing the time for free exploration of the simulation are improvements made as a result of the findings of the pilot study.

In the dissertation (phase two of the research design) these findings were implemented in a new curriculum scaled for 85 new students from the same school during the next school year. The modifications included new components implementing simulations as an assessment tool for all students and embedded modeling tools. All students were asked to build pre and post models, however due to technological constraints these were not an effective tool. A non-video group of 44 students was established and another group of 41 video students had a WISE curriculum which

iii

included twelve minutes of scientists' conversational videos referencing explicit aspects on the nature of science, specifically the use of models and simulations in science. The students in the video group had marked improvement compared to the non-video group on questions regarding modeling as a tool for representing objects and processes of science modeling aspects as evident by multiple data sources. The findings from the dissertation have potential impacts on improving Nature of Science (NOS) concepts around modeling by efficiently embedding short authentic scientific videos that can be easily used by many educators. Compared to published assessments by the American Association for the Advancement of Science (AAAS), due to the curriculum interventions both groups scored higher than the average United States middle school student on many NOS and climate content constructs.

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DEDICATION

I would like to dedicate this work to my mother and all of my students that I have taught thus far. Each has taught me so much in my lifetime and I feel truly blessed to have some so many warm rich memories to reflect upon.

	P	AGE
ABSTRACT	ГШ	I
ACKNOWL	EDGEMENTSV	
DEDICATIO	DNV	II
TABLE OF	CONTENTSV	III
LIST OF TA	ABLESX	Π
LIST OF FIG	GURESX	III
CHAPTER		
I.	INTRODUCTION1	
II.	LITERATURE REVIEW4	
	2.1. What is science?4	
	2.1.1. What is current authentic science?4	
	2.1.2. Ways in which to teach NOS	
	2.1.3. What NOS should be taught in schools?10	0
	2.1.4. Use of technology10	C
	2.2. Climate change content	2

TABLE OF CONTENTS

	2.2.1. Alternate conceptions about the greenhouse effect and climate change
	2.3. Students use of simulations in classroom15
	2.3.1. Benefits of using simulations16
III.	PILOT STUDY20
	3.1. Rationale derived from the literature review
	3.2. Pilot study
	3.2.1. Pilot study methods
	3.2.2. Pilot study data collection and analysis
	3.2.3. Pilot study findings24
IV.	DISSERTATION METHODS
	4.1. Overview
	4.1.1. Method modifications
	4.1.2. Pre/post test analysis
	4.1.3. Interviews
	4.1.4. Coding scheme
	4.1.5. Simulation adjustments
V.	FINDINGS
	5.1. Overview
	5.2. Establishing models and simulations as scientific tools40
	5.2.1. Breadth of understanding of model usage41

5.2.2. Video group moved to a more complex view of				
models as predictive in nature				
5.3. How are students' content understanding altered by the curricular changes?				
5.3.1. Improving content understandings during "Extreme				
Testing" simulations44				
5.3.2. Causal relationships45				
5.3.3. The greenhouse effect influence on climate change47				
5.4. Changes in NOS understanding				
5.4.1. Modeling as limited to objects50				
5.4.2. Input and output data				
5.4.3. NOS and student growth54				

6.1. Discussion
6.1.1. Overall learning gains59
6.1.2. Establishing models and simulations as scientific tools
6.1.3. Improving understanding during "Extreme Testing"61
6.1.4. Why should simulations and models be used to teach NOS?61
6.2. Limitations
6.3. Implications
6.4. Future Research70

REFERENCES	
APPENDIX A	
APPENDIX B	

APPENDIX C	
APPENDIX D	84
APPENDIX E	90
APPENDIX F	94

LIST OF TABLES

Fable 1 Adopted nature of science framework dimensions	1
Table 2 Pilot student descriptions 2	1
Table 3 Analysis method of research questions	0
Γable 4 Questions from AAAS that are used in this study3	4
Table 5 Mean scores on the ten content pre/post questions4	.3
Table 6 Mean scores on the eight NOS pre/post questions 4	.8
Table 7 Which of the following could be represented with a model? Table shows the	
percentage of Students that answered that question. (Answered in pairs during	
WISE curriculum)5	1

List of Figures

Figure 1 Climate change simulation from WISE software	23
Figure 2 Screen capture of WISE 4.0 greenhouse effect simulation	38
Figure 3 Mean of pre/post test for content	44
Figure 4 Mean scores on NOS pre/post test	49
Figure 5 Which of the following can a model represent?	52
Figure 6 Question 31 AAAS average compared to research groups	56
Figure 7 In what ways can a model or simulation be different than what is suppose to represent?	57
Figure 8 "My System" example from step 1.10	64

CHAPTER 1: Introduction

With increased public attention (and debate) around climate change, many science teachers and curriculum developers are seeking ways to help students understand the science of this complicated topic. As part of the solution to this challenge, technology tools can help students visualize, understand and apply climate science concepts while engaging in authentic scientific practices. This designed-based research focuses on how students use a greenhouse effect simulation, embedded within an inquiry-based technology-mediated science curriculum, in conjunction with an emphasis on explicit scientific methods and process of modeling. A pilot study was conducted and the dissertation research herein takes into account those findings.

Learning is a complex interplay between cognitive (individual and group), social, psychological, contextual, cultural, and societal factors. From a pedagogical perspective, experiential (hands-on), inquiry-based curricula have emerged as productive approaches to teaching science (NRC, 2005; 2007; Davis & Linn, 2000; White & Frederickson, 1998; Zimmerman & Stage, 2008). Though there is some dispute over the effectiveness of inquiry-based pedagogical approaches (c.f., Kirshner et al., 2006; Hmelo-Silver, Duncan, & Chinn, 2007). Empirical evidence supports the use of inquiry in classrooms (Hmelo-Silver et al. 2007). This study employs a definition of inquiry that views science learning as a complex treatment of both science content and science inquiry practices (Hmelo-Silver et al., 2007). In recent years, educational researchers have successfully utilized a combination of educational technologies for engaging students in inquiry-based science learning activities (Slotta & Linn, 2009). For example, the Webbased Inquiry Science Environment (WISE - see http://wise.berkeley.edu) offers

1

numerous inquiry tools such as drawing, graphing, data tables, concept mapping, online discussions and student journals to support researchers who wish to create such curriculum to embed their questions about learning and instruction (Linn & Hsi, 2000; Slotta, 2004; Slotta & Linn, 2009).

Computer-based simulations and models are said to be the most powerful advancements in math and science since the Renaissance (Bransford, Brown, & Cockling, 2000). In education, computer simulations and models are sometimes grouped, or the terms are used interchangeably. For consistency in this paper, the term *virtual models* is used to describe digital recreations of real-life phenomena that contain preset, non-changeable parameters, also referred to as animations in other publications, and the term *simulation* is used to describe digital recreations that allow for user interaction with the real-life phenomena being portrayed in the simulation. Therefore, simulations allow users to manipulate the variables and thus the outcomes. For example, students can manipulate the degree to which solar energy is reflected by different features of Earth's surface, also known as *albedo*. When students manipulate all of the variables that make up the total system, the causal relationships found are referred to as *system dynamics*.

The research described herein follows a practitioner inquiry paradigm and designed based research. Practitioner inquiry, a broad category of educational research methodologies that includes action research, teacher-researcher and other similar approaches, describes situations "where the practitioner is the researcher, the professional context is the research site, and the practice itself is the focus of study" (Cochran-Smith & Donnell, 2006, p. 503). In teacher-researcher methods, the classroom teacher is also

the researcher. As the classroom teacher and doctoral student, the relationship between subjects and researcher is vastly different than a sole researcher. The prior knowledge about the subjects' content knowledge and personality can lead to insights often unattainable by an "objective" researcher. Data sources such as teacher-researcher's notes are collected within context of the classroom and changes exhibited by the subjects (i.e., the teachers' students) are easily recognized.

The dissertation research involves analyzing modifications to the curriculum based upon the pilot study. These modifications include new video components on the NOS with an emphasis on explicit connections between authentic scientists' simulations and student simulations to answer the following research questions:

1) How does an "Extreme Testing" pedagogical approach improve student comprehension and explanation of complex climate system dynamics?

2) How does inclusion of embedded videos of scientists discussing authentic use of computer simulations affect student understanding of the nature of science (NOS)?

3) How are students' understanding of the greenhouse effect's influence on global warming altered by the curricular changes?

CHAPTER 2: Literature Review

2.1. What is science?

As an undergraduate student, the ability of science to stimulate discussion fascinated me. This fascination lead me to the library at a large east coast university where the eight foot high book shelves overflowed with volumes of books about what science is and has been over the centuries. After filtering through the first three stacks of dusty material, I realized why science lacks simple answers. Philosophers, religious scholars, science educators, and even scientists themselves have been pondering this question since the days of the Enlightenment. Today, "What is science?" has become an important component of both teacher education programs and K-12 science education (Lederman, 2007; Duschl, Schweingruber, & Shouse, 2007). With so many different ideas over the years as how to teach science, what students are expected to know and how to teach authentic science becomes convoluted.

2.1.1. What is current authentic science?

One major stumbling block for building conceptual understanding of climate change is students' understanding of how science works. The topic of climate change is not only problematic for science students to comprehend; it is also an important topic for citizens outside of the scientific community, as well. *"Climate Change* and the Integrity of Science" is a recent letter signed by over 250 National Science Foundation scientists in regards to the public and political issues related to the understanding of the Nature of Science and the content of climate change (Gleick, 2010). "All citizens should understand some basic scientific facts. There is always some uncertainty associated with

scientific conclusions; science never absolutely proves anything" (Gleick et al., 2010, p.1). This is one fundamental idea that makes up the Nature of Science (NOS). What science is, and how science works is defined as the NOS by the AAAS (The American Association for the Advancement of Science, p.4) in the following description:

"Over the course of human history, people have developed many interconnected and validated ideas about the physical, biological, psychological, and social worlds. Those ideas have enabled successive generations to achieve an increasingly comprehensive and reliable understanding of the human species and its environment. The means used to develop these ideas are particular ways of observing, thinking, experimenting, and validating. These ways represent a fundamental aspect of the nature of science and reflect how science tends to differ from other modes of knowing. It is the union of science, mathematics, and technology that forms the scientific endeavor and that makes it so successful. Although each of these human enterprises has a character and history of its own, each is dependent on and reinforces the others."

In the past fifty years, as students have entered and exited science classrooms,

many have left with an imprinted specific scientific method and format that scientists supposedly follow. The American Association for the Advancement of Science (AAAS) has lobbied to improve the conceptual understanding of NOS including 'Methods of Science.' The more specific steps of the scientific method have metamorphosed to a more abstract 'Methods of Science' model involving various cycles and feedback loops. Osborne et al. (2003) gathered politicians, philosophers, scientists, science teachers, and leaders from the educational world in an attempt to end the debate by summarizing the best scientific methods. Project 2061 created a framework as to what aspects of scientific methods, history, and social aspects should make up national standards (Osborne, 2003; McComas & Olson, 1998). More recently, educational leaders, cognitive scientists, and philosophers of science have met to establish consensus on the inquiry of science and how that consensus affects science teaching (Duschl, Schweingruber, & Shouse, 2007). Educational leaders have recently created documents providing clear and explicit instructions from the findings of researchers into friendly, easy to read publications for teachers. One example, Taking Science to School; Learning and Teaching Science Kindergarten to Eighth Grade (TSTS) provides many recommendations to improve education (NRC, 2007). Another example, the Next Generation Science Standards (NGSS) are the proposed standards based upon research on learning and teaching science which, as of the publication of this paper in 2013, are currently being finalized and prepared for state adoption.

TSTS research recommendations include understanding the nature and development of scientific knowledge (NRC, 2007). Beginning teachers' ideas of doing science is strongly grounded in the standard notion of the scientific method, while ideals pertaining to claims, arguments, alternative explanations, and models were non-existent (Windschitl, 2004). Textbooks also have a similar backbone of a scientific method that is rigid. Duschl et al. (2007) summarizes the findings of the conference discussing the Nature of Science that a new method of science model needs to be adopted by institutions from kindergarten and beyond.

Determining what constitutes the Nature of Science (NOS) is a complex task. Driver et al. (1996) view the nature of science as encompassing a common core of ideas about commitments, methods, and practices. Science is not only a process for making sense of the natural world, but it is also shaped by the people who construct explanations about it. Science is affected by people, their culture, ideas and creativity (Akerson et al., 2000). Communicating this and related understandings to students is important for supporting a more sophisticated understanding of science (Driver et al., 1996). A naïve understanding of NOS can provide students with "ammunition to dismiss" a credible scientific theory as students impose inappropriate evidential requirements that lead to false conclusions (Dagher & BouJaoude, 2005, p. 387).

2.1.2. Ways in which to teach NOS

Students cannot implicitly gather what scientists do or how scientists work by just doing science, they need to be taught the methods and history of science for best practice (Duschl et al., 2007; Gordin, Pea, & Edelson, 1999). Many textbooks teach the scientific method in the beginning of the book and leave the rest of the book free of the methods, with some sprinkling in the history of science across other chapters. Students need to be reminded during lessons what scientists do and how they do it (Lederman, 2007). This not only makes the tasks more authentic but increases motivation for students.

Lederman (2007) explains that there is a difference between didactic teaching of Nature of Science and explicit teaching. When students are taught in a didactic way, they are being told exact aspects of NOS, the aspects are reviewed, discussed, and then assessed. For an explicit accurate teaching model, the information should, however, first be gathered from the students through discussion or curriculum where their prior knowledge has become apparent. Once that information is available to all participants, an explicit way of teaching the NOS is through examining how those NOS thoughts and beliefs are similar or different to how scientists view their scientific work. Having student ideals that mesh or correlate with authentic scientific views through the curriculum would be an example of successful explicit teaching.

2.1.3. What NOS should be taught in schools?

There is an ongoing discussion about what aspects of the Nature of Science are most appropriate for inclusion in school science (Stanley & Brickhouse, 2001; Osborne et al., 2003; McComas & Olson, 1998). Science educators have used different approaches to determine a core set of NOS ideas that are appropriate for school science. For example, McComas & Olson (1998) extracted a consensus of NOS views from eight international science standards documents including the United States National Standards and AAAS Benchmarks. The authors found consensus on concepts such as: scientific knowledge while durable has a tentative character; there is no one scientific method; science is an attempt to explain natural phenomena; and science and technology impact each other. Tao (2002), proposed five major NOS ideas: scientists usually work in collaboration, one followed by another; scientists carry out experiments to test their ideas, hypothesis, and theories. Careful and systematic studies are not enough, there must also be creativity; scientific theories are constructed by scientists to explain and predict phenomena; and lastly, science knowledge, while durable, has a tentative character.

Allchin's (2004) conception of NOS emphasizes the fallible nature of science. He acknowledges that science is factual in its attempts to solve problems and explain phenomena. However, values do become a part of science no matter how objective the scientist is. Allchin (2004) further points out that scientists use a variety of methods such as hypothesis, analogy, and induction. Some scientists collect observations while others recognize patterns in data. Imagination, logical reasoning, chance, and interdisciplinary thought can all be important. This, in a way, summarizes all the processes that are taken into account when scientific methods are discussed, while still stating that scientists use a

8

variety of methods. In an effort to settle issues raised by a much contested study by Alters (1997), Osborne et al. (2003) conducted a Delphi study, in which the authors sought the opinions of twenty-three experts from the fields of science education; scientists, philosophers of science, sociologists of science, science educators and science teachers. The experts were asked to state their views regarding three individual questions pertaining to what they thought about the methods of science, the nature of scientific knowledge and the institutions and social practices of science (Osborne et al., 2003). The nature of science themes derived in the Osborne et al. study are classified under three dimensions: Nature of Scientific Knowledge, Methods of Science, and Institutions and Social Practices in Science. In table 1, the adopted NOS framework dimensions and themes are based primarily on Osborne et al. (2003) with noted support from other researchers. The cross references are not meant to be exhaustive, but represent exemplars in the field.

Table 1. Adopted	nature	of sci	ence fra	amework	dimens	sions

I. Nature of Scientific Knowledge	
A. Science and Certainty	
(Driver et al., 1996; McComas & Olson, 1998; Tao, 2002)	
B. Historical Development of Scientific Knowledge	
(McComas & Olson, 1998; Duschl et al., 2007)	
C. Cumulative and Revisionary Nature of Scientific Knowledge (Allchin, 2004; McComas, 1998)	
D. Status of Scientific Knowledge	
(Akerson et al., 2000; Driver et al., 1996; Tao, 2002)	
E. Science as Human, Collaborative Activity	
(Driver et al., 1996; Duschl et al., 2007; Tao, 2002)	

II. Methods of Science	
 A. Scientific Methods and Critical Testing (Allchin, 2004; Driver et al., 1996; Duschl et al., 2007; Lederman, McComas & Olson, 1998; Tao, 2002) 	2007;
B. Analysis and Interpretation of Data (Duschl et al., 2007; Ledermen, 2007; Tao, 2002)	
 C. Hypothesis and Prediction (Akerson et al., 2000; Driver et al., 1996; Duschl et al., 2007; Lede 2007; McComas & Olson, 1998; Tao, 2002) 	rman,
D. Diversity of Scientific Thinking (Lederman, 2007; McComas, 1998)	
E. Creativity (Allchin, 2004; Duschl et al., 2007; Lederman, 2007; McComas & Olson, 1998; Tao, 2002)	
F. Science and Questioning (Allchin, 2004)	
G. Observation and Measurement (Allchin, 2004; Duschl et al., 2007; McComas & Olson, 1998)	
H. Specific Methods of Science (Allchin, 2004; Lederman, 2007)	
F. Distinction Between Science and Technology (Allchin, 2004; McComas & Olson, 1998)	
I. Cause and Correlation (Allchin, 2004; Duschl et al., 2007; Lederman, 2007)	

2.1.4. Use of technology

Driver et al.'s (1996) analysis of student ideas about the images of science reveals an interesting view of science; when asked to draw a scientist, students in the past have drawn a male in a white lab coat doing experiments...normally an older white male, using beakers. Students think of scientists' tools to be hands on manipulative medium. During the pilot run of the curriculum used in this dissertation research, students were asked, "What are examples of scientific tools?" They responded similarly with answers such as test tubes and chemicals. Over the past 20 years, technology has increased tremendously and has infused into every aspect of science, more recent drawings of science and scientists still include beakers and chemicals used by a white coated scientist. The students still do not think of new technologies, such as computer simulations to be scientific tools. Duschl et al. (2007) commented that disconnected hands on lessons and textbooks have been a staple of science classes during the past 50 years. Classroom instructional time is used to examine what we know based on the textbook or the teacher's instruction. Relevance to meaningful authentic science is minimal. Scientists now use more technology in their work than ever before. Scientists have "move(d) from a static model in an inert medium, like a drawing to dynamic models in interactive media that provide visualization and analytic tools is profoundly changing the inquiry in mathematics and science" (Bransford et al., 2000, p.215). Students need to understand how models and simulations work and that they are human endeavors. Models are based on the scientists' idea and scientists are the ones that input data in the models. Outputs of the models are relative solutions depending on how the scientist set up the parameters of the model. As variables are adjusted by the scientist, models and simulations can produce complex outcomes due to the vast computing power of new technologies.

Concord Consortium asserts that models are at the core of any scientific theory and that model construction and deployment are fundamental, if not the most fundamental, processes in scientific inquiry (Wieman, Perkins, & Adams, 2007). "A scientific model is defined as a conceptual system mapped, within the context of a specific theory, onto a specific pattern in the real world so as to reliably represent the pattern in question and serve specific functions in its regard. A model may serve an exploratory function (pattern description, explanation, postdiction and/or prediction), and/or an inventive function (non-video or change of existing physical systems to produce the pattern, and/or pattern reification into new physical systems and phenomena)." (Halloun, 2004).

2.2. Climate change content

"There is compelling, comprehensive, and consistent objective evidence that humans are changing the climate in ways that threaten our societies and the ecosystems on which we depend" (Gleick et al., 2010, p.689). Global warming is the idea of an unnatural change in global climate. A better term is climate shift, which refers to areas that use to be dry and are now more wet while other areas that were wet have become drier (Flannery, 2006). Unfortunately, recent reports and research on people's understanding of the science that underlies climate change are rather disheartening. The Pew Center on Global Climate Change recently grades 25% of citizens in the United States with an F for their content knowledge about climate change (Leiserowitz, Smith, & Marlon, 2010). Other reports claim that the basic science content related to climate change is vastly misunderstood by the general population (IPCC, 2005). Additionally, several research studies on students' understanding of climate science reveal deep and lasting misconceptions (Corliss & Spitulnik, 2008; Lysack, 2009). Together, these studies point to the need for improved climate change education.

2.2.1. Alternate conceptions about the greenhouse effect and climate change

The greenhouse effect visualization has a large amount of content knowledge. This abundant content can become problematic. During an analysis of teacher questioning and involvement using the WISE global warming simulation, Corliss & Spitulnik (2008) recorded that the teacher noticed many student misconceptions at the beginning of the climate change simulation. Misconceptions or alternate conceptions are ideas about scientific phenomena that students have accepted as an accurate solution and therefore are a pivotal problem when trying to build new accurate understanding on this prior knowledge. Many student and adult alternate conceptions exist about the scientific phenomena of our planets' temperature regulation system (Lysack, 2009). Currently, basic science content related to climate change is vastly misunderstood by the general population (IPCC, 2005).

In 1997, there was an investigation of middle school science students' understanding of climate change, the hole in the ozone layer, and the greenhouse effect (Rye et al., 1999; Osterlind, 2005). Students believe the hole in the ozone is a major cause to climate change (Rye et al., 1999). Students also believe that global warming is caused by pollution (Rye et al., 1999; Osterlind, 2005). They include trash or litter as causes of global warming along with air pollution (Osterlind, 2005). The greenhouse gases that make up the atmosphere do come from human pollution, but most are natural like water vapor, Carbon Dioxide, and methane.

Since there are numerous alternate conceptions around global warming, what is the content knowledge that students should be able to comprehend? The students need to understand concepts such as photosynthesis, radiation and atmospheric gases in order to understand global warming (Osterlind, 2005). These basic science terms are found in the state standards for middle school students and are fundamental aspect in climate change. Photosynthesis is a major regulator of carbon in the atmosphere as is the deep ocean (Flannary, 2006). Plants get energy from the Sun by radiation. Radiation is how energy is transferred through the atmosphere from the Sun (Flannary, 2006). The deep ocean can hold four hundred times more carbon than the atmosphere. The plants that use the Carbon Dioxide and thus reduce excess Carbon Dioxide in the atmosphere also affect the greenhouse gases (Osterlind, 2005).

Overall, there is a shift to a higher world temperature. Students believe this is a tiny temperature change and state that it does not feel different, but when provided a comparison between their normal temperature of 98.6 degrees Fahrenheit with a temperature during a sickness at 100 degrees Fahrenheit and above, students might realize how a small change can make a large difference. This is the same amount the world temperature is predicted to increase over the next hundred years (Bindoff et al., 2007; Leiserowitz, Smith, & Marlon, 2010). The temperature increase makes all gas and water molecules move further apart because now they have more kinetic energy. When vast volumes of water in the ocean expand due to thermal heating, the increase in water height is significant. Since average ocean depth is around two miles, there is a great amount of room for thermal expansion that can greatly affect the coast of every country (Bindoff, 2007). This concept is largely not discussed when students are being taught about ocean rise predictions. Most students' descriptive explanations of the increase in ocean height center on the melting of frozen fresh water.

Parts per million is a mathematical concept that people have trouble visualizing. This is extremely apparent in climate sciences where the debate begins to analyze atmospheric gases (Flannary, 2006). Nitrogen and Oxygen account for 99% of the gases in Earth's atmosphere. The remaining one percent contains the major greenhouse gases, including methane, Carbon Dioxide, water vapor, hydrogen, and helium. Albedo is one fundamental construct of greenhouse and climate change models, and a factor that can be tied to human impacts. Albedo refers to the reflective power of any surface. The scale for the albedo coefficient is 0-1, where a 0 indicates that all light energy is absorbed and none is reflected (e.g., a black surface) while a 1 indicates complete reflection (e.g., a white surface). For example snow has a score of 0.9 while dark soil has one of the lowest scores of 0.05 (Flannery, 2006). The greatest change in albedo is happening at the poles. Previously, the polar regions were covered with white glaciers that reflected seventy percent of the Sun's energy. When that ice melts, the dark ocean now at the surface absorbs an increase in heat energy (Flannery, 2006).

Many people believe that due to their white color, clouds reflect more sun rays (Leiserowitz, Smith, & Marlon, 2010). However, it is not the color but more the amount of water that clouds are filled with that affect heat capacity in the atmosphere (Leiserowitz, Smith, & Marlon, 2010). Droplets in clouds reflect solar radiation and absorb long wave radiation.

2.3. Students use of simulations in classroom

Interactive Simulations are a new way to engage students in educational activities and teach scientific ideas (Wieman et al., 2007). These simulations follow the model of eliciting prior knowledge, constructing new information, evaluating ideas and explaining those ideas within their new context. Weiman et al. (2008) has created over sixty simulations for use in scientific fields, a majority of which are in the area of physics. In a seven month period from January to July in 2007 over 2.25 million simulations were run online (Wieman et al., 2008). An unknown amount, but most likely a much larger portion of these simulations were downloaded and rerun (Wieman et al., 2008). These educational tools are receiving much more attention from educators and the research community. Lowe (2006) stated interactive animations have become commonplace in the educational setting. Interactive animations include any type of animation that allows the user an element of non-video. The ranges in classrooms vary from students choosing what sections of an animation to watch, to creating a complex model of the solar system. Simulations that are used as visual models have been viewed for over thousands of hours with students and teachers across all socio economic classes and location (Kali & Linn, 2008). When students can manipulate things, they can then begin to explain what is happening with these physical scaffolds. Students can create predictions in their heads; the tool allows students to making their thinking visible.

2.3.1. Benefits of using simulations

Simulations, when used properly, can increase student motivation, prediction skills, visualization, modeling, engagement, content knowledge, and scientific understanding (Chang, Quintana, & Krajcik, 2009; Casperson & Linn, 2006; Linn, Davis, & Bell 2004; McElhaney & Linn, 2008). Pea (2006) found the human mind can quickly process and remember visual information and therefore concrete graphics and other visual information can help people learn. When students can manipulate things, they can then begin to explain what is happening easier. Students can create predictions in their head, the simulation tool used in this dissertation research allows students to making their thinking visible. One benefit of using simulations is the motivational influence on students' desire to engage and interact with the learning tool. Previous practices such as teaching with a textbook have left students discouraged and uninterested in science (Kali & Linn, 2009). However, students are very motivated and engaged during simulation activities (Casperson & Linn, 2006; Chang, Quintana, & Krajcik, 2009; Edelson, 2005; Kali & Linn, 2009). Simulations are used from the elementary to college level as a way to increase interest in the way concepts are being taught. The cookbook labs, or labs that follow a set recipe with little student manipulation, where everyone is expected to end with the same exact perfect product is an unrealistic view of science not apparent in simulations (Kali & Linn, 2009). Now students can adjust the variables and create the path in which their learning follows. They begin to get ownership of their learning progressions. This student-centered learning aspect is viewed as one reason why students self reported the green house simulation to be extremely engaging (Corliss & Spitulnik, 2008).

Not only are the simulations engaging, high quality simulation can prepare students for the learning of abstract concepts more effectively than direct field experience (Winn et al., 2005). When students were on a research vessel doing population sampling versus doing a virtual population sampling, students in the virtual simulation world had greater leaps in content understanding compared to the ship board group (Winn et al., 2005). There are other benefits to using simulation as opposed to being on the research vessel such as its cost effectiveness versus the cost of being on a ship with a group of students. The simulation can be used in any weather while the ship experience is greatly affected by weather. Therefore many more students, at any time of day or location across the United States, can do the virtual simulation as opposed to the real-world learning context. This is true for many simulations vs. real world experience scenarios. Another major difference between the two situations is now in the virtual simulation the student can see below the water while ship board students cannot. This visual aspect is a major strength of simulations.

Students can construct a "robust conceptual understanding" by using computer simulations (Squire et al., 2003). The human mind can quickly process visual information and "that suggests that concrete graphics and other visual representations of information can help people learn" (Bransford et al., 2000, p.215). Simulations have a great amount of visual stimulus that allow for conceptual formations. Students can build an understanding due to the display of dynamic graphics to engage visual learners (Lowe, 2006). "Research has shown that technology-enhanced visualizations can improve inquiry learning in science when they are designed to support knowledge integration. Visualizations play an especially important role in supporting science learning at elementary and middle school levels because they can make unseen and complex processes visible" (Kali & Linn, 2009).

All of that visual information can become extraneous information and needs to be removed in order to allow information at the readiness level of the students to become apparent. Current research on computer simulations argues the model-based experience will allow patterns to be observed more easily only when data is simplified (Winn et al., 2006). Simulations can have an abundant amount of content knowledge that the learners need to focus on, simulation creators need to recognize this and limit the scope of the visualizations (Wieman et al., 2008).

Learning could be improved if students are allowed to create models or simulations to portray their understanding of the climate. Duschl and Grandy (2012) explain that a better version of explicit NOS teaching advocates students engage in domain- specific scientific practices during multi-week long curriculum units. The units should focus the learners' attention on aspects of scientific knowledge through model building and refining such as; measuring, observing, arguing from evidence, and explaining. World climate change has many feedback loops and interconnected processes that are difficult to put into words and can be better depicted by students and scientists using simulations (McCaffrey & Buhr, 2008).

CHAPTER 3: Pilot Study

3.1. Rationale derived from the literature review

Many students fail to understand major concepts connected with climate change, as do 52% of adults (Leiserowitz, Smith, & Marlon, 2010). The NOS, or the way in which scientists conduct their work has been attacked due to a lack of understanding by citizens and congress (Gleick et al., 2010). In addition, many science curricula, state science standards, and individual teachers do not include climate change topics in school (IPCC, 2007). A recent National Earth Science Teacher Association poll provided research that a majority of teachers do not feel comfortable teaching climate education nor do they have the resources needed to teach those concepts (personal communication, December 12, 2012). With the lack of knowledge and education around climate change, how can citizens make adequate decisions regarding the climate future? In order to better prepare students, and thus future adults, a focus on pedagogical approaches and science content needs to be undertaken. Inquiry-based simulations have shown promise for helping people understand complex abstract systems phenomena and for learning content knowledge (Casperson & Linn, 2006; Chang et al., 2009; Linn & Eylon, 2006; McElhaney & Linn, 2008). A curriculum for middle school students' abilities to learn the greenhouse effect through an inquiry-based simulation where students can manipulate variables to observe predicted outcomes was analyzed for climate science content and NOS growth during the pilot study.

3.2. Pilot study

Seven 8th grade students participated in all aspects of this research. The small class size contained a very diverse intellectual spectrum from high achieving to low

achieving students. The class also had the schools' most disenfranchised learner who was the leading scorer in discipline referrals. These students were diverse across gender, academic achievement, and ethnicity. The enrollment of the suburban Northeast middle school where this research took place is 40% African American, 25% Caucasian, 25% Asian, and the remaining 10% is mixed with a majority of Spanish speaking students. These seven students represent the diversity of the classroom. The current 8th grade curriculum is primarily earth science with a strong emphasis in chemistry. Meet the students:

Table	e 2. P	ilot	stud	ent o	des	cri	pti	ons	3
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Nevin	Always smiling and answering questions with descriptive responses.
Diego	A struggling learner that continuously wants to improve and asks "Why?" often.
Ivana	High achieving student that is a pleasure to teach.
Rhianne	The quietest girl, she is reluctant to share ideas and discuss thought process.
Sam	He may be the brightest student, but he is also difficult to motivate.
Erica	Smiles and works well with Rhianne. She helps her discuss the ideas presented.
Harsh	Always involved in everything going on in class, academic and otherwise.

3.2.1. Pilot study methods

The sample size for this study was chosen based on previous research on student use of simulations and evaluation for technology design (Wieman, Adams & Perkins, 2009). In the PHET physics modeling research, after simulations are created, six students are given the simulation to "interact with" (Wieman et al., 2009). It is argued that after the first six students use the simulation any additional students only replicate previous findings without adding new findings (Wieman et al., 2009).

This research utilized an already designed and tested week-long WISE curriculum focused on scientific concepts of global warming with a strong emphasis on knowledge integration from the use of a simulation on the greenhouse effect. The curriculum design was guided by Scaffolded Knowledge Integration framework (Linn, 2005). Participants took part in a three week-long WISE science curriculum. The students have used the WISE curriculum previously during their school year and were comfortable with the platform. The WISE greenhouse simulation (see Figure 1) was the focus of examination and occurred on day three of the curriculum. Students worked in pairs on the computer while one student chose to work on his own.

The simulation provides a model of the greenhouse effect that students can manipulate as they change certain variables, see Figure 1. Students have the ability to adjust clouds, sunlight, albedo, and/or Carbon Dioxide by increasing or decreasing the amount of each variable. Each change will then affect the world temperature and thus the graph that accompanies the simulation. Students can also track one Sun ray to make it easier to see the interaction of the Sun ray amongst other variables. In order to complete the task at hand, students can stop, start or reset the simulation as many times as they wish.



Figure 1. Climate change simulation from WISE software. http://wise.berkeley.edu/

JING software was used to capture student audio as well as any screen manipulations during student use of the simulation. The JING recordings were presented to students during semi-structured interviews, and students were asked to explain their thinking and actions as they interacted with the simulation. Olympus D50 portable, digital voice recorders equipped with Olympus noise-cancelling lapel microphones were used to capture students' conversations during the lessons and interviews. A digital voice recorder was also used during the focus group.

3.2.2. Pilot study data collection and analysis

The complementary sources of data were: (a) seven pre-/post curriculum questionnaires, (b) student written responses captured within WISE during the
curriculum, (c) observations, including teacher-observer notes, (d) JING software-digital videos of audio and screen capture recordings of *in situ* conversations and computer manipulations during the curriculum, (e) a focus group during the curriculum to develop further analysis questions for the open-ended interviews, and (f) post curricular open-ended interviews having students analyze and explain their manipulation and conversations captured by the JING software during their simulation usage.

Since there is little documented data on how students learn using a simulation in Earth Science, an open qualitative approach was the best method to undertake (Maxwell & Loomis, 2003). The research methodology followed a qualitative study approach, including various avenues of examination to determine student understanding of climate change and the use of simulations (Creswell, 2003; Maxwell & Loomis, 2003). The qualitative data come from interviews as students manipulate the simulation, teacherresearcher field notes (Creswell, 2003), a focus group, and JING recordings. A focus group was conducted with seven students to observe group discussion around the use of the simulation as a research tool and to look for similarities in student ideas as a basis for future coding.

3.2.3. Pilot study findings

A computer simulation can shift student's perceptions of science content and their beliefs about simulations as real scientific tools. Mixed responses still existed at the end of the study. For example, students still struggled with the idea of delayed (noninstantaneous) reactions of the system. This is not unlike learning without a simulation. However, some simulation-specific results point to important pedagogical considerations. For example, findings about students' ideas about the nature of science, lead to recommendations of strengthening the prior nature of science instruction to include simulations, this can improve students' beliefs that simulations are authentic scientific tools.

By allowing students to visually see and point out the difference in normally unseen phenomena, abstract scientific concepts become concrete. For example, in the cloud description, the sunrays were described as "jelly beans bouncing" by Sam and as "bumper cars" by Diego. Students can now relate to familiar visual experiences and more difficult concepts such as the interaction among the gases in the atmosphere. Allowing students opportunities to make personal connections to abstract phenomena can help them better explain their ideas, leading to increased learning opportunities (Linn & Hsi, 2000).

The human mind can quickly process visual information and "that suggests that concrete graphics and other visual representations of information can help people learn" (Bransford et al., 2000, p.215). When students state they liked the simulation's color representations (e.g., solar radiation as yellow) and ability to adjust parameters, it is reflective of current notions of learning with simulations. By repeatedly watching the sunlight bounce around, students constructed an understanding of how the increase in clouds can lead to a cooler world, especially during the post interview. These students concluded that clouds reflected thermal energy back into the atmosphere when there was no mention of any cloud effects during the greenhouse effect or climate change in any of the pre tests.

According to Edelson (2005), most curricula overlook motivation and time for refinement as critical aspects of learning. The case study supports this notion of the

25

importance of student motivation. Sam's surprise around the learning aspects of the simulation, "Wow, we really learned doing this; when we use computers, we normally don't learn." is related to motivation. He later explained that he was more interested in doing the task and that the simulation was "fun." His partner added, "It was really cool; you could make a lot of clouds and fill the screen with clouds, then watch the energy bounce around." By allowing students time to reflect and work with the simulation, they were able to refine their thinking, and their discoveries were self-motivated.

Many students thought that clouds reflect sunlight back to Earth, which is partly accurate. One student explained that if the clouds are higher they reflect light more, while clouds that are lower act like Carbon Dioxide, making "heat bounce back to Earth and keeping it warm." The student most likely meant thermal energy when they said the word "heat". When probed further about why clouds can reflect thermal energy, students stated because they are "white and fluffy" or "white things reflect light so clouds reflect sunlight back just like ice does." These statements are partly true. They visually saw this occur, but without explicit reasoning as to why the Sun's rays interacted with the clouds in this manner, students created their own reasoning. When students are left to create their own learning, however, further inaccuracies can be established that may lead to future learning difficulties (Azvevedo, Guthrie, & Seibert, 2004). One example is the omission of water as a greenhouse factor. This omission may be contributing to students' partial understandings of water vapor as a greenhouse gas.

A constraint of the greenhouse simulation, as it was constructed, is the choice to exclude water vapor as a factor. Methane, Oxygen, water vapor, and etc... are all valid greenhouse gases. As with all modeling decisions, educational researchers must choose

which components are included and which ones are not included in order to reduce the complexity of the model for the students (c.f., Pea et al., 1999). In this case, the educational researchers chose to exclude water vapor from the simulation. Educational research has shown that in order to promote student learning, choices about levels of complexity must be carefully considered. All of that visual information can become extraneous information; model based experience will allow patterns to be observed more easily only when data is simplified (Winn et al., 2006). Learners also can have difficulty focusing on the extreme amount of content knowledge. Simulation creators need to recognize this and limit the scope of the visualizations (Wieman et al., 2008).

During teacher-researcher observations, it was observed that the students naturally tried to adjust variables right away and overload the simulation. For example, Neil said, "I added lots of clouds and watched the sun rays bounce around there. The whole screen was filled with clouds it was crazy, the sun ray couldn't get out." They thought it was really fun to block the sunlight out. This is similar to models of the Gerard et al. (2008), Learning Cycle: eliciting current ideas, adding new ideas, evaluating ideas, and sorting out ideas. Following their natural inclination, part of the interview process had students do "Extreme Testing" (e.g., making the world as hot or cold as possible). It provided them with results that allow students to realize the true values of each variable and how they correspond with other significant variables. Scientists do these extreme model simulations when looking at scientific processes such as sea level increases. Asking students to destroy the world makes them think about how difficult it would be to actually destroy the world in the simulation. What variables would they physically have

to adjust to make the worst possible scenario? This complex task is fun and natural for them while they have to critically analyze all the system dynamic specifics.

The pilot study found that students did not see the simulation as a scientific tool, despite the increased use of simulations by scientists (Gray & Szalay, 2007). During the pilot study interviews, only one out of seven students stated that they believed simulations are scientific tools. Corliss & Spitulnik (2008) reported preliminary observations that students did see that the simulations could be used for predicting the future, which is a limited portrayal of the NOS (Duschl et al., 2007). There are many more aspects of NOS that are present in the WISE simulation that students did not recognize. For example, models can be used to share information among colleagues, show complex system analysis, and be used as tools to explain hypothesis (Duschl et al., 2007).

The complexity of simulation turned out to be challenging for struggling students. Some students saw the simulation as overwhelming due to the amount of information. Scaffolding and focusing students on different aspects of the model allows for a reduction in the task complexity (Gerard et al., 2008). However, our students did not use the builtin WISE scaffolds. The students did not read any directions, nor refer back to previous screens to help them with the task. Even though these built-in scaffolds and help buttons were present, the students either asked the teacher-researcher or tried to randomly guess on their own. Only in one instance did a student go back to a previous informational screen in order to reevaluate the task. Questions remain as to the need for greater external scaffolds to help reduce the task complexity.

CHAPTER 4: Dissertation Methods

4.1. Overview

Following a design-based research model, this dissertation study utilized a standards-based inquiry science curriculum once again using the WISE Global Warming curriculum. The research described herein follows a practitioner inquiry paradigm. Practitioner inquiry, a broad category of educational research methodologies that includes action research, teacher-researcher and other similar approaches, describes situations "where the practitioner is the researcher, the professional context is the research site, and the practice itself is the focus of study" (Cochran-Smith & Donnell, 2006, p.503). Creswell's (2007) qualitative methods handbook notes that the teacher-researcher's "extensive time spent in the field, the detailed thick description, and the closeness of the researcher to participants in the study all add to the value or accuracy of the study" (p. 207).

Iterative curriculum design provides opportunities to refocus research, "As conjectures are generated and perhaps refuted, new conjectures are developed and subject to test...The intended outcome is an explanatory framework that specifies expectations that become the focus of investigation during the next cycle of inquiry" (Cobb et al., 2003, p.10). Phase two of this design process is the dissertational research in which according to the iterative design, newly created pedagogical approaches included allowing students to conduct "Extreme Testing" and increasing the time for free exploration of the simulation were implemented in the dissertation. Data collection involved multiple forms of complementary data: data analysis, examined audio and video

29

recordings of interviews and observations, pre and post tests, WISE curriculum, in-situ video capture (JING), and "My System" models made on WISE.

	Data Source	Data Analysis	students
R	Pre/post test, JING	1a)Record using JING initial use simulation and	10
Е	video capture, "My	variables as currently set up	
Α	on WISE,	1b) model	85
S	student interviews, WISE curriculum	1c)Before Interview- Explain how the greenhouse works using simulation and model.	10
Е	capture, teacher notes	1a2) Record again using JING during "Extreme	
Α		Testing" as formative assessment	10
R		1b2) new model	85
C		1c2) After Interview- Explain how the	10
Н		greenhouse works using simulation and model.	
0			
1			
Q	Pre/post test, JING	2a) Code for focus on the creative, predictive,	85
2	video capture, "My	replicable, systematic, and representative nature	
	System" models made	of modeling, aspects on the Nature of Science.	
	on WISE,	2b)Interview and pre post test question about	85
	student interviews,	are simulations scientific and why	
	WISE curriculum		
	capture, teacher notes		
Q	Pre/post test, JING	3a)Pre/Post multiple choice quantitative	85
3	video capture, "My	analysis	20
	System" models made	3b)Qualitative analysis of explanation of global	
		warming and greenhouse effect pre/post	
	student interviews,	curriculum	
	WISE curriculum		

Table 3. Analysis method of research questions

		capture, teacher notes	
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4.1.1. Method modifications

Findings from the pilot study were scaled up to 85 students at the same school and curricular scaffolding was created based on identified student deficiencies from the pilot study. One of the major improvements is that all students now have an "Extreme Testing" scenarios implemented in their curriculum. It was observed that students naturally tried to destroy the world during the pilot study. The addition of "Extreme Testing" reflects this finding and is also true to how authentic scientists use simulations to test extreme conditions. Graduate Student Scientists interviewed at Rutgers College of Marine and Coastal Sciences referred to this ability in simulations as the "god factor," a way to play god safely (personal communication, September 20, 2012). For example during their research, the Rutgers Graduate Student Scientists create volcanic eruptions as a way to simulate increased greenhouse gases in the atmosphere (personal communication, September 20, 2012). This is a normal authentic scientific exercise that can only be conducted through simulations. Concord Consortium's Global Warming curriculum has students use the simulation to mimic a Snowball Earth type environment, a similar task but without the explicit NOS instruction or follow up questions (personal communication, November 22, 2012). Based on the conversations with authentic Rutgers Graduate Scientists, staff at Concord Consortium, and observations from the pilot study; all students conducted "Extreme Testing" scenarios as an assessment piece to make the world as hot and as cold as they possibly could within the context of the simulation provided.

A major finding from the pilot study was that students did not think that using the simulation was a scientific task. There was no student discussion about modeling observed during the pilot study. Despite the implicit student use of a computer simulation, students' responses did not correlate or include a connection between modeling and what they did in class (Cohen & Zimmerman, 2012). These observations lead to a recommendation for the dissertation study to include student opportunities to create a stagnant model of the greenhouse effect. These stagnant models are made using the WISE "My System" tool. Students create the model prior to any simulation usage and at the end of the unit. As part of the stagnant model, instead of Carbon Dioxide being the focused greenhouse gas, the WISE "My System" tool consists of molecular models which include Carbon Dioxide, water and Oxygen. Students use the modeling tool to explain how the greenhouse effect works prior to using the simulation and then after simulation usage in both curriculum groups.

The video group and non-video group differed in the addition of twelve minutes of NOS videos in the video group's curriculum. The videos consist of a 5 minute video made to explain the background of virtual modeling and simulation from a technological conference perspective by *Frontier Scientists*

(http://www.youtube.com/watch?feature=player_embedded&v=zExRvlaLZbU) and the researcher-created 7 minute videos of two scientists discussing major aspects of modeling. The video group had embedded videos starting after the initial "My System" model. The first video (see Appendix E) explains how scientists use computer modeling and simulations in order to evaluate scientific questions related to climate. Teacher-researcher made videos included dialogue between various scientists discussing which

variables to adjust and the benefit of using a computer simulation. The short videos focus on the creative, predictive, replicable, systematic, and representative nature of modeling. These specific NOS aspects are found to be the most necessary in student NOS learning (Lederman, 2010; McComas & Olson, 1998; Osborne, Collins, Ratcliff, & Miller, 2003; Stanley & Brickhouse, 2001). This explicit teaching with strong curricular connections to scientists' use of virtual modeling in their authentic work and student creation of greenhouse effect models was expected to provide an increase in student understanding of virtual modeling as a scientific task. See appendix E for a complete description of the embedded videos and where they were located in the WISE curriculum.

4.1.2. Pre/post test analysis

For the pre/post test creation of the NOS questions, some questions were obtained from the new AAAS Science Project 2061 online test bank. All pre/post test questions are in Appendix A and the answers are in Appendix B. The video and non-video student responses were correlated to the national percentages for middle students. According to AAAS these multiple choice questions differ by assessing students' conceptual understanding, testing for common alternate ideas, and are precisely aligned to the science idea they are intended to test (http://assessment.aaas.org/pages/about). The questions created and utilized by the AAAS for national field tests were split into sub ideas and key ideas based on researched alternate conceptions. Items were written to align with target learning goals. Pilot test data was reviewed by assessment specialists, scientists, science teachers, and other science educators before field testing to obtain norming data. Questions 25, 31, and 33 were used in analysis of NOS learning. Table 4. Questions from AAAS that are used in this study

Question 25. In what ways can a model or simulation be different from the thing it represents?

- A. A model can be a different shape than the thing it represents, and it can be a different color.
- B. A model can be different shape than the thing it represents, but it must be the same color.
- C. A model can be a different color than the thing it represents, but it must be the same shape.
- D. A model must be the same shape as the thing it represents, and it must be the same color.

Question 31. A student wants to make a simple model of the solar system to help him compare how long it would take for a spaceship to travel between different planets. Which of the following things is essential for him to do in order to think about how long it would take?

- A. He must make sure that the model of each planet looks like the planet it represents, but he does not need to accurately represent the relative distances between the planets because the most important thing is that models look like the thing they are modeling.
- B. He must accurately represent the relative distances between the planets, but he does not need to make sure that the model of each planet looks like the planet it represents because only the relevant aspects of the thing being modeled need to be modeled accurately.
- C. He must accurately represent the relative distances between the planets and also make sure that the model of each planet looks like the planet it represents, because a model should be as much like the thing being modeled as possible.
- D. He does not need to accurately represent the relative distances between the planets and he does not need to make sure that the model of each planet looks like the planet it represents, because there are always some differences between a model and the thing being modeled.
- Question 33. An engineer made a simulation of a ship to help him think about how it works. He made sure that some characteristics of the ship were accurately represented, but he did not include all of the ship's characteristics in his model. Is it okay that he ignored some of the ship's characteristics? _____A
- A. It is okay, but only if he represented the characteristics that affect how the ship works, because models need to include the characteristics that are relevant to what is being studied.
- B. It is okay, but only if he represented the characteristics that affected whether the model looks like the ship, because models should look like the things that they

represent.

- C. It is okay, but only if he represented the characteristics that people would be interested in knowing about, because models are only used to communicate information to others.
- D. It is not okay that he ignored some of the ship's characteristics. A model should be like the object it is representing in every way possible.

4.1.3. Interviews

A cross section of the class was selected for the interview process. There were 20 students selected, ten students from the non-video group and ten students from the video group. Each group had six girls and four boys which was representative of the 58% female to 42% male ratio in the total course. There were three pairs of students selected from each of the four course sections except for the first period course where two pairs were selected. A range of students was chosen based on their academic achievement. Each group had 3 high achieving students and three low achieving students, with 4 students per group in the subset of average achievers. The interviews were focused on content and NOS understanding, for all interview questions, as shown in Appendix C.

JING is screen and audio capture software which is free and already on student computers. The interview process used JING to capture students making the world as cold as possible while they talk through their reasoning for variable change in the "Extreme Testing". This was later coded and analyzed to provide a qualitative addition to the quantitative analysis of pre/post testing. Fraser and Tobin (1992) explain the rationale for a combined method:

...the complexity of qualitative observational data and quantitative data added to the richness of the data base as a whole...Through triangulation of quantitative

data and qualitative information, greater credibility could be placed in findings because they emerged consistently from data obtained using a range of different data collection methods (p. 290)

4.1.4. Coding scheme

The interview coding scheme was iteratively developed and built upon the recommendations from the pilot study. The code for content of "What is the greenhouse effect?" and "How does it work?" was broken down into the three parts according to the proposal recommendations that "Part of the explanation should be how energy arrives as solar radiation, is conducted, and turned into thermal energy. Then when being emitted from Earth, the energy is now infrared radiation" (personal communication, March 29, 2012). During analysis of the interviews, vignettes were classified at the question level in various groupings. The whole student response was examined for content and NOS coding. After explaining the coding to two other raters and clarification of the codes, 40% of the sample was coded together. An inter-rater reliability of 97.5% was obtained. Once the inter-rater reliability was obtained, then exemplars were identified and presented as shown in Appendix F.

The three main content concepts students are expected to learn are albedo, greenhouse effect, and simulations. Students need to explain the albedo effect and what characteristics of Earth affect albedo. Expected answers should include the-high reflectivity for ice, snow, and clouds. Open Ocean has a low albedo and farm land is about average albedo. The greenhouse effect is a concept that students should be able to explain. Lastly, students should know how simulations are made and that scientists use simulations. This aspect of the NOS was divided into 5 subsets for coding: creative, predictive, replicable, systematic, and representative aspects of science. Originally, each term was coded separately showing relative low explanations during the interviews that used key ideas of NOS. However when all five codes were looked at as a whole, a broader picture of student understanding was observed where, out of 20 interviewed students, 16 used at least one of the 5 simulation codes during their explanations.

4.1.5. Simulation adjustments

Since the pilot study using WISE 2.0, a newer version of WISE 4.0 has been released. The new version of the curriculum contains changes that implements some of the recommendations previously stated. The new simulation now splits the variables and reduces the amount of written directions for the students. Some other modifications include reducing visual overload by allowing the user to choose to follow an energy packet or greenhouse gas, as well as reducing the amount of moving molecules on the screen to ten percent of the total. Further updates include a temperature graph and a major greenhouse gas graph. Multiple data points in one simulation are more authentic to current NOS and will be addressed in scientist video discussions. Instead of written directions, authors use screen shots of the model and then arrows or bubbles pointing to what students should see and do. This alleviates questions or difficulties from reading comprehension, but it may also decrease the inquiry nature of the tasks.

A constraint of the previous greenhouse simulation was the choice to exclude water vapor as a factor. Methane, Oxygen, water vapor, and etc... are all valid greenhouse gases. As with all modeling decisions, educational researchers must choose which components are included and which ones are not included in order to reduce the complexity of the model for the students (c.f., Edelson et al., 1999). In this case, the educational researchers chose to exclude water vapor from the simulation. Educational research has shown that in order to promote student learning, choices about levels of complexity must be carefully considered. However, the newer version from WISE 4.0 (see Figure 2) does include more complexity and variables which may add confusion for students. The curriculum has four variations of the same simulation that increase in complexity as students complete aspects of the curriculum. The final simulation (see Figure 2 below) contains all of the variables. The key ideas from the developer Robert Tinker (personal communication, November 22, 2012) include:

- 1. Energy is conserved. There are three types of energy: 'sun-rays', 'heat things', and 'IR rays' (infrared radiation). All of these contain the same amount of energy.
- 2. Sunrays can reflect off clouds and can be reflected or converted into heat at the surface, depending on the albedo.
- 3. The temperature graph is proportional to the number of 'heat things' in the Earth.
- 4. 'IR rays' can be absorbed by clouds and Carbon Dioxide
- 5. Carbon Dioxide moves in the atmosphere and can be absorbed in the land or water with arbitrary probabilities. Carbon Dioxide in the water can enter the atmosphere sink to the ocean bottom.
- 6. If the temperature drops below zero, ice advances and when the temperature rises above zero the ice will retreat.



Figure 2. Screen capture of WISE 4.0 greenhouse effect simulation

CHAPTER 5: Findings

5.1. Overview

A paired-samples t-test was conducted to compare understanding in the pre tests of the video and non-video groups. There was no significant difference in the pre test scores for video group (M=8.05, SD=2.48) and non-video group (M=7.24, SD=2.90) conditions; t (40) =1.44, p > .05. These results suggest that the groups were consistent in their prior understandings of the content. After the curriculum, the same assessment was administered with all students as a post test. A paired-samples t-test was conducted to compare understanding in the post tests of the video and non-video groups. There was no significant difference in the post test scores for video group (M=10.07, SD=3.40) and non-video group (M=9.78, SD=2.40) conditions; t (40)=0.46, p > .05. These results suggest that the video group did not have significant learning gains over the entire post test when compared to the non-video group. Therefore individual questions are analyzed to show learning gains between both groups.

Students in the video group had marked improvement compared to the non-video group on questions regarding modeling as a tool for representing objects and processes of science modeling aspects. This is evident from multiple data sources. Interviews reveal that students recalled phrases and explanations from scientist conversations that helped them understand the nature of modeling. Analysis of the interview participants, a subset of total student participants, reveals the video group had a ten percent increase over the non-video group, demonstrating that there is strength in the NOS videos.

When all 85 students were examined as a whole group for their growth in learning some major findings were revealed. Overall, there was statistically significant improvement in learning. A deeper look into individual questions shows that when compared to student assessment results published by the American Association for the Advancement of Science (AAAS), both groups scored higher than the average United States middle school student on many NOS and climate content constructs.

Many of the "My System" models from the WISE curriculum were inconclusive for student learning. Even though all students were asked to build pre and post models, due to technological constraints these models were not effective pedagogical or evaluation tools. The models that were saved and could be examined for pre/post curricular growth did not correlate to pre/post test findings.

5.2. Establishing Models and Simulations as Scientific Tools

The primary aspect of modeling as a representative function was discussed during the pre-interviews. Results of these interviews yielded that students had an incomplete understanding of the many facets of modeling and simulation usage by scientists. During the pilot study, students repeatedly stated simulations were not scientific tools and in order to "do science", scientists needed to manipulate apparatus in a lab setting like beakers or test tubes (Cohen & Zimmerman, 2012). During the dissertation research, students interviewed from the non-video and video groups, both explained scientific ways in which scientists use simulations. Eight out of ten students prior to the curriculum in the non-video group believed simulations were scientific tasks, and all but one agreed in the post interview. However, all of the students in the video group believed modeling and simulations were scientific task. Ethan explained, "Scientists use simulations by observing the process of an object or what happens with the object if you do this or that with it," or they are used "to test out what is happening." Since this amount of prior knowledge was vastly different than the pilot study, the interview transcripts were coded for modeling and split into five subsets: creative, predictive, replicable, systematic, and representational aspects of science. Sixteen students during pre-interviews (nine from video group and seven from the non-video group) referred to the representative aspect of models and simulations. Many students used words like they "show" or "demonstrate." Other students referred to the fact that models and simulations can "easily represent ideas." Four students overall did mention more than one of the other codes during their interviews. Three students during the pre-interview felt that models and simulations were predictive tools while only one mentioned the replicable nature of simulations.

5.2.1. Breadth of understanding of model use in science

The video group had a greater breadth of understanding than the non-video group on aspects of modeling and simulation usage as a result of the interventions. More students commented on various aspects of simulations in the post interviews. Interestingly, in the post-interviews of the non-video group, there were minimal changes in students' thinking. Most non-video group students still had a simplified view of models, viewing them as largely only used in science as representative, but during the post interviews three non-video students also thought models and simulations reduce time of the scientific process or made scientific tasks quicker. For example, Adam stated "Scientists use simulations, for example glaciers, they don't have thousands of years to study one glacier so they just use a simulation to speed up time and see what happens, that way they finish a study faster than if they did it at first hand." This idea of using simulations to speed up the act of science was not present in any post interviews from the video group. Since the simulation itself models climate change and can predict how the climate may react 100 years or further in the future, students may have perceived how simulations can reduce the time of scientific studies as they manipulated this specific greenhouse effect simulation. Perhaps without the video explanations clearly laying out the general use of virtual modeling and scientific simulations as they relate to the time of the scientific process, the bigger picture of simulation use was missed by some non-video group students.

5.2.2. Video group moved to a more complex view of models as predictive in nature

Robust ideas of what constitutes a simulation were successively improved upon within the video group. For example, during the WISE curriculum Susana wrote, "A model or simulations is used to show small features of an object larger or vice versa." Later in her post interview she stated, "A model is a 3-D representation of an idea on a smaller scale used to see if the idea's structure is stable. Using a simulation or model is a scientific task because you are building, and creating experiments to see the outcome of an event." Susana has moved from just believing the model is a representational tool as she did in the pre-interview, now she is beginning to change her thinking to include the predictive nature of modeling. Unsolicited, three students explained the predictive nature of modeling during the interviews while only one student from the non-video group used predictive nature in their explanations.

5.3. How are students' content understanding altered by the curricular changes?

Student understanding was measured using a pre/post test (see Appendix A). The test was split into two sections: one section with content questions and one section with NOS questions. Paired t-tests were used to compare the pre and post tests of the non-video group and video group. There was significant difference in the non-video group scores for pre test (M=7.18, SD=2.90) and the post test (M=9.73, SD=2.34) conditions; t (43)=-5.78, p < .001. There was also significant difference in the video group scores for the pre test (M=8.05, SD=2.48) and the post test (M=10.07, SD=3.40) conditions; t (40) =-3.69, p < .001. The first section consisted of ten multiple-choice questions to measure content understanding. Students had greater growth on the content aspects of the test. On these ten questions, the mean score for all students was slightly above six out of a total possible score of ten, showing that climate change is still a difficult topic for middle school student comprehension even post curricular intervention (see Table 5 and Figure 3).

Group	Mean Pre	Standard	Mean Post	Standard	Pre to	P Value
_	Test	Deviation	Test	Deviation	Post	
	Content		Content		Test	
	Scores		Scores		Gain	
Non-video	3.95	0.28	6.04	0.30	2.09	0.13
Video	4.43	0.27	6.13	0.26	1.70	0.18
Total	4.19	0.16	6.08	0.22	1.89	0.08
Students						

Tab	ole	5.	Mean	scores	on	the	ten	content	pre/	post	quest	ions
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Figure 3. Mean of pre/post test for content

Individually, there is minimal difference between the video group and non-video group in their learning growth of content knowledge. Over this small sample of questions, these findings do illustrate a difference in content understanding based on the total curriculum. One aspect where curricular gains were recorded was during student interviews while using the "Extreme Testing" assessment piece.

5.3.1. Improving content understanding during "Extreme Testing" simulations

During the pilot study, students, without prompting, made the world as hot or as cold as possible during their initial interactions with the simulation. I noticed these natural inclinations of the students and made a request of students to try making the world as hot and as cold as possible during the JING video captures. The simulation and "Extreme Testing" discussion is illustrated in this vignette:

- Mr. Cohen: "So, you are getting rid of the Carbon Dioxide and you're adding....so you're taking away sun brightness and there is no albedo. So, the temperature rapidly dropped from 70 to 15 degrees. But now it is stable at 15 [degrees]. Why did the temperature stabilize?"
- Rhianne: "Because there is nothing else moving around and the heat energy is trapped in the Earth. So, what's left above the Earth is what's going to be there until Carbon Dioxide is added and sun brightness is added."
- Mr. Cohen: "So, if you add to Carbon Dioxide and sun brightness, what's going to happen?"

Rhianne: "The heat [is] going to go up."

The simulation tool allowed for an avenue to promote scientific discussion of causal relationships. This proved to be so promising that as the curriculum was reworked for the dissertation study, the concept became one of the research questions: How does an "Extreme Testing" pedagogical approach improve student comprehension and explanation of complex climate system dynamics? Students in both groups conducted the extreme testing scenarios as an assessment piece to the curriculum. During the "Extreme Testing" videos, a think-aloud protocol, were students explain their thinking and verbalize their thought processes as they made the world extremely cold and hot, was used. The students captured this data themselves using the JING software. Many students did this recording of information in the hallway or in another classroom so the audio could be recorded without background interference.

5.3.2. Causal Relationships

As students discussed their thinking, students were able to use the video of how they used the simulation as they explained causal relationships, this provided support in student explanations. Students who did an adequate job and explained in depth during the recordings had a richer analysis of the recordings when they watched them later. These students were able to provide quality causal relationships from both the non-video and video group. One example was when Vinnay said, "Making high albedo and a lot of green house gasses means that the 'world' became a lot hotter. When we made albedo 100% and added many clouds and took out all of the green house gasses then it became colder." When looking at Vinnay's initial pre test around these concepts and his later post test related to albedo and greenhouse effect, there is an improvement on each task. Perhaps this usage of the extreme testing scenario provided that growth in his learning. Another student that showed improvement on these concepts was Ahmed. During his "Extreme Testing" scenario he stated:

"Infrared radiation affects the model by increasing heat in the atmosphere, as long as it is trapped in it. Carbon Dioxide and other greenhouse gases affect the temperature by trapping reflected infrared radiation in the atmosphere. Albedo affects the world temperature by reflecting more radiation if it is high (decreasing the temperature), and by reflecting less and absorbing more radiation if it is low (increasing the temperature). The simulation responded in this way, it represented what would happen in real life, and was sufficiently accurate."

He was the only student that placed a value on the quality of the simulation related to real life. His causal relationship was accurate. His evaluation of the simulation as a scientific task even though not elicited, provides an interested foray into the students' ideas about the NOS.

Steven also provided an example of growth in causal relationship understanding, during his interview utilizing JING videos. In the pre-interview he said he did not know how infrared radiation interacts with the greenhouse effect. During the post-interview he was able to explain that, "Infrared radiation affects the model by cooling the Earth when it exits or heating when it stays. Carbon Dioxide and other greenhouse gases affect the temperature by trapping infrared rays in the Earth. Albedo affects the world temperature by either reflecting Sun rays or absorbing them"

5.3.3. The greenhouse effect influence on climate change

Some students thought the greenhouse effect had to deal with a real greenhouse and prior to the curriculum did not associate the term greenhouse effect with how Earth regulates global temperature. For example, Jemilia was building a more complex understanding as the curriculum progressed. At first when asked, "What are the consequences of greenhouse effect on human beings and on the planet Earth?" She responded, "The greenhouse effect both helps and harms human beings and planet Earth in general. The greenhouse effect causes your car to get hotter than it is outside on a windy day." This is exactly what she typed in the WISE curriculum when questioned about unequal heating about a closed car on a sunny day. Understanding that the greenhouse effect can be both good and bad is accurate; however she did not explain why she thought that. Her content idea of a car heating up from the greenhouse can be considered correct if that was the question being asked. It is possible she was stating content that did not relate to the question since she was not sure of a correct question response. She then moved to a more complex understanding while using the simulation realizing there was a correlation between greenhouse gases and global temperature to answer the same question, "What are the consequences of greenhouse effect on human beings and on the planet Earth?" Jemilia explained, "The more greenhouse gasses are the hotter it will be. So, if there is more green house gasses the global temperature will rise."

5.4. Changes in NOS understanding

How student comprehension of NOS was modified due to inclusion of the scientist videos will be presented in this section. This analysis refers to research question 3: How does inclusion of virtual modeling tools and scientist discussion of authentic simulation process skill application through embedded curricular videos effect student Nature of Science understanding?

How students thought progression and accuracy on the NOS was modified during the curriculum was measured numerous ways. One way was on the second half of the pre/post test. Eight questions were asked that directly related to NOS (see Table 6 and Figure 4). When individual questions from AAAS are analyzed in future sections of this chapter, both groups of students often outperformed the AAAS average score results for middle and high school students.

Group	Mean Pre	Standard	Mean Post	Standard	Pre to	P Value
	Test NOS	Deviation	Test NOS	Deviation	Post	
	Scores		Scores		Test	
					Gain	
Non-video	3.27	0.16	3.70	0.13	0.43	0.60
Video	3.63	0.27	3.95	0.28	0.32	0.61
Total	3.45	0.16	3.82	0.18	0.48	0.45
Students						

Table 6. Mean Scores on the Eight NOS Pre/Post Questions



Figure 4. Mean scores on NOS pre/post test

The importance of establishing models as a scientific tool was essential to the student's understanding to the Nature of Science. However, before the video experiment, many students were unfamiliar with this concept as demonstrated in the following interaction in the classroom.

Jovanni: "Oh that's sick! Is that a simulation?" Robert: "No that is a diagram." Teacher: "Why do you think this is a diagram and not a simulation?" Robert: "It doesn't provide specific data." Jovanni: "It doesn't provide data over time?"

Prior to viewing the videos, the students experience confusion about qualities that constitute an accurate scientific simulation. The students struggle to define specific components, engage in collaborative discussions, and demonstrate higher level thinking. After the videos, students are able to understand the data and identify that scientists make data meaningful. The students are then able to negotiate which types of data can be evaluated for scientific understanding. As demonstrated by the vignette below, students can identify simulations are dependent upon scientists' current knowledge.

- Sama: "Male scientists' models are representative of what he thinks we know so if we don't know much at the beginning we need to add more as we go."
- Nadia: "He was studying the ocean, but he doesn't know where every little thing is. He doesn't know where the dust goes or comes from; the models are only based on what he does know."

5.4.1. Modeling as Limited to Objects

Another major alternate conception in modeling is that only an object can be represented and not a process. This idea was tested during lesson 8.8 of the WISE curriculum after watching the six video segments explicitly teaching ideas of the NOS (see Appendix E). During the curriculum there was minimal improvement in the non-video group on this question. At the beginning of the WISE curriculum, the non-video group earned a correct rate of 52% and after step 8.8 without the aid of NOS videos there was a slight increase to 55% accuracy (see table 5). There was still significant strength in the alternate conception of "models can represent an object but not a process" for the non-video group much higher than the national AAAS average of 30%.

For the same question, the video group had an increase of 14% for the correct response, "Both an object and a process can be represented in models." In the pre test, they earned a score of 70% and moved to a post test score of 84%. Even though the video group started below the AAAS average of 30% for the alternate conception "models can represent an object but not a process" with a pre curriculum rate of 20%,

remarkably after the treatment, that alternate conception was reduced to 0. This shift

from the alternate conception to the more accurate response accounted for the majority of

the percentage point change for the video group.

Table 7. Which of the following could be represented with a model? Table shows the percentage of Students that answered that question. (Answered in pairs during WISE curriculum)

Pre/Post An object b		A process, but	Both an object and a	Neither an
	not a process	not an object	process CORRECT	object nor a
			ANSWER	process
AAAS	30%	8%	57%	5%
AVG				
Pre Non-	44%	4%	52%	0%
video				
Post Non-	45%	0%	55%	5%
video				
Pre Video	20%	0%	70%	10%
Post	0%	10%	84%	6%
Video				



Figure 5. Which of the following can a model represent?

While looking at Figure 5, it becomes extremely evident that the video group not only outperformed the other groups, but also the curricular modifications reduced students picking the major alternate conception of this multiple choice item to zero. This is about a 20% decrease in the same alternate conception which remained constant for the pre and post test of the non-video group.

5.4.2. Input and output data

The idea of an input and output table was mentioned or discussed in four different interviews without prompting. Patti pointed behind her during the video segment "Input and Output" to show an input and output table. She used hand motions to describe atmospheric input and output of data while Steve explicitly explained how he used ancient dust data to predict future climate. When further discussion took place Jemilia explained that, "If you put trash in the model, then you get trash out." This is a direct quote from Steve when he explained models and that model processes are only as good as the data placed in the model. Steve said, "If you put trash in then you get trash out." Randy further explained this concept in his notes under "Model Validity" which he wrote, "We learned that if you put garbage into a model you will receive garbage out. A way to prevent this is to get good data sets and make sure that they are accurate. To make sure to prevent this type of garbage, you should have good data measurements." This analogy resonated with the students providing adequate understanding that modeling is only of objects but can be a process using the idea of inputting and outputting data.

According to the AAAS website

(http://assessment.aaas.org/items/MO038004#/0), question 33 (see Figure 6) is testing if it is "acceptable and sometimes beneficial for a model to lack features of the real thing that are not relevant to what is being studied". The correct answer for the question is A. Nationally 37% of middle school students were correct on this question and 44% of high school student were correct. The non-video group had a pre test score of 23% correct and post test of 27% correct. This showed little change in their understanding due to the WISE curriculum. The video group started still below the national average at 34% but had a post test score of 51%, a 17% increase for the video group and 14% above the national average of middle school students for accuracy and 7% above the high school national average on this question.



Figure 5. 17% increase on question 33 of video group compared to AAAS average

During the interview, video group student Randy explained that, "In the videos the scientists drew on the board and they were pretty bad drawings, but they were focused on good data in and good data out, not the color or how the simulation looked." These ideas show a direct correlation between the scientist video discussion and the above average increase on this question. During the videos scientists focused upon what makes a good model and were aware of the alternate conception held by many students that models need to look like what they are representing.

5.4.3. NOS and Student Growth

Overall the students increased on their content and NOS understanding by 24% from pre- to post-test. Most questions on the post test showed no statistically significant

difference between the non-video group and video group. There was above a 20% post test understanding on question 31 (see figure 6), for both groups when compared to the AAAS average for middle school students on this question. The non-video group increased their understanding post curriculum by 19% while the video group improved 18%.



Figure 6. Question 31 AAAS average compared to research groups

The increase in both groups understanding can be correlated to the input of stagnate model building as part of the new WISE curriculum. When building the model students realized it was a simplified example of the real greenhouse effect and did not look like the real greenhouse simulation, but that the focus was on connections between the aspects of the variables in the greenhouse effect. For example in the teacherresearcher notes, during explanation of how to use the "My System" tool, Andrew asked, "So you mean I don't have to draw the greenhouse effect here, you just want us to show the connections between the different parts of the greenhouse effect, like how the Earth gets energy from the sun and then we use the arrow to show that and it leaves as infrared." Andrew and others then understood the goal of the model was to not make it look just like the object or event, but to represent the process it was modeling. That was the major alternate conception found by AAAS when using this question.

When examining the NOS growth on the pre/post tests, an interesting phenomenon was discovered on question 25, (see Figure 7). Students in the video group outperformed the non-video group and almost doubled their student growth from the pre test. Even more surprising, and the only instance in the pre/post test data, was the nonvideo group actually did worse on the post test then the pre test.





Student growth due to curricular changes in NOS understanding for the video group compared to the non-video group for question 25 can be seen not only from interview coding, where a disproportionate amount of non-video students believed that models are representational in nature compared to a more robust understanding during post interviews for video group students, but with a closer analysis of interview statements. These interviews reveal the lack of complex understanding in models as representational tools. For example, Lela stated, "Freedom tower had little 3-D models at a bigger scale for an actual object, this school came to be from the models made for it." She and many other students focused on the visual aspect and scale that models require. In the videos scale wasn't a driving force as much as simulations and models need to represent the ideas or goals that the scientist is building the model for. For example, Steve Hovan, one of the scientists in the videos, explains that when modeling ancient dust patterns the really important aspect is how accurate the models can be at demonstrating where the dust particles have moved and predicting future dispersion patterns.

CHAPTER 6. Discussion, Limitations, Implications

6.1. Discussion

6.1.1. Overall learning gains

Students in both groups had measurable learning gains that were statistically significant. This is similar to findings from other researchers on the use of inquiry-based, technology-mediated simulations which have shown promise for helping people understand complex abstract systems phenomena and for learning content knowledge (Casperson & Linn, 2006; Chang, Quintana, & Krajcik, 2009; Linn & Eylon, 2006; McElhaney et al., 2008). Learning gains for this study were greater on content learning than on NOS understanding. This is possibly due to the nature of the material being taught. Climate change is a relatively new topic for many 8th grade students while the nature and process of science is a large unit in 6th grade science at this school. Students have multiple lessons and lab inquiry experiences with NOS concepts taught throughout their middle school experience. Based on students' prior knowledge, a larger growth for content understanding is expected.

6.1.2. Establishing models and simulations as scientific tools

Despite the increased use of simulations by scientists (Gray & Szalay, 2007), the pilot study found that students did not see the simulation as a scientific tool. In the dissertation research students did believe initially simulations were scientific tasks. Corliss & Spitulnik (2009) reported preliminary observations that students did see simulations as scientific tools which could be used for predicting the future. Duschl et al., (2007) found there to be limited portrayal of the NOS in schools. A portion of the
students in this study also believe models and simulations are scientific tools useful for making scientific predictions, more so after the initial scientist videos. They also began to see the complex nature of predictions and the use of simulations as a tool for reproduction of findings which was not previous reported in the simulation literature review.

The findings from this research suggest that computer simulated programs can shift student's perceptions of simulations as real scientific tools and how simulations and models can be utilized by scientists. This is impressive for an intervention that cumulatively accounted for a mere twelve extra minutes within a two-week-long curriculum. Students struggled with the idea of delayed (non-instantaneous) reactions of the system but showed improvement and understanding during "Extreme Testing" scenarios.

As evident in Figure 5, the video group not only outperformed the other groups but including the videos reduced students' alternate conception about, modeling and simulations being only used for objects but not a process, to zero. During the video segment of scientists discussing input and output, they use the word "process" to explicitly describe what models can represent. Randy wrote, "During the model video in 3.5, Patti said you use models to show processes and they can show both models doing process at the same time." Even though the second segment of the statement is not as clear, the first part of the statement provides evidence that the video group recalled explicit aspects of the modeling discussion presented by Patti, one of the scientists in the videos. During the video, she alluded to the fact that multiple models can be used to show scientific process and that may be what this group was referring to. This leads to a more complex understanding that a model may serve an exploratory function (pattern description, explanation, post-diction and/or prediction), and/or an inventive function (Halloun, 2004).

6.1.3. Improving understandings during "Extreme Testing" simulations

World climate change has many feedback loops and interconnected processes that are difficult to put into words and can be better depicted by students and scientists using a visual representation (Sperling, 2003). The "Extreme Testing" scenario provided students this ability to explain their thinking. They now could explain in greater analysis with more content knowledge and more understanding of the causal relationship between greenhouse gases and temperature. Bransford et al. (2000) would agree that this manipulation of the simulation allowed for more robust understanding and explanation. Students can construct a "robust conceptual understanding" by using computer simulations (Squire et al., 2003). The human mind can quickly process visual information and "that suggests that concrete graphics and other visual representations of information can help people learn" (Bransford et al., 2000, p.215). These robust responses were more evident in the interviews compared to the embedded WISE responses. Findings suggest responses in WISE do not elicit the breadth and depth of student understanding as compared to the interviews. The interviews had greater advantages for understanding student thought process. WISE has many advantages, however like any teaching tool, it has its weaknesses and thus a triangulation of data is necessary (Fraser & Tobin, 1992).

6.1.4. Why should simulations and models be used to teach NOS?

61

Students self reported that simulations were motivational and improved understanding around modeling. This data can be used with teachers and researchers for future curriculum implementation (Edelson, 2005). This research is essential for improving the ways we teach and learn about climate change, we need to continue to explore best practices for teaching these ideas. "Research has shown that technologyenhanced visualizations can improve inquiry learning in science when they are designed to support knowledge integration. Visualizations play an especially important role in supporting science learning at elementary and middle school levels because they can make unseen and complex processes visible" (Kali & Linn, 2009). As students used the simulation in the video group, their robust understanding of scientist modeling became evident during their interviews and "Extreme Testing" assessments. These learning gains are invaluable as a large amount of the world's attention has turned toward the phenomena of global climate change. Many students fail to understand major climate change concept as do 52% of adults (Leiserowitz, Smith, & Marlon, 2010). However, research on student understanding of climate change, or best practices of climate change instruction is yet to be fully explored. Curriculum that provides learning gains around the greenhouse effect and public understanding of the scientific endeavors that scientists undertake to accurately research climate change is a large gap in current research. Most research points to the difficulties students' have differentiating the greenhouse effect and from the hole in the ozone layer (Koulaidis & Christidou, 1999). The lack of comprehension between the change in greenhouse gas production and the systematic lag of a decrease greenhouse effect is evident in the research and these simulations address those concerns (Koulaidis & Christidou, 1999).

The current WISE global warming curriculum was modified to increase more NOS explicit content discussion between scientists and it showed improvement. These video segments were made on board the JOIDES Resolution deep sea drill ship and involved scientists discussing how they use modeling and simulation in their work. The students can build greater understandings due to the video's ability to display dynamic graphics to engage visual learners (Lowe, 2006). There are no similar videos with this explicit authentic instruction available to students and these can be a model for future curricular modifications for similar learning gains.

6.2. Limitations

The study contained few limitations. The limitations included; the prior knowledge of the teacher, a need for explicit questioning around model limitations, the "My System" modeling tool, and inconsistent video quality.

The scope of the study was in one middle school classroom where the teacher researcher conducted a pilot study and utilized the WISE software previously for various curriculums, providing prior experience much greater than the average teacher. Implementing these lessons in other classrooms may necessitate professional development for the instructor. However, due to the nature of the WISE curriculum, the scientists embedded videos can be easily utilized across vast classroom variations with consistency of NOS concepts.

During the interviews, students alluded to the accuracy of the simulation as it depicts real scenarios. Explicit interview questions about the accuracy of the simulation as a depiction of real life may reveal students' thoughts. Some students discussed ideas similar to limitations or strengths of models during the curriculum. These ideas were not coded for or asked about, but could be easily assessed in future uses of the same curriculum if explicit questions on this topic were added to the interviews or WISE curriculum.

The embedded assessment in WISE, "My System" as a pre test in section 1.10 and then as a post test in section 8.1 proved to be a problematic assessment piece and did not unveil student thinking (see Figure 8).



Figure 8. "My System" example from step 1.10

Explain to Gwen how the Earth is warmed by energy.

Be sure to include the following information as you LABEL ALL ARROWS:

- Where energy comes from
- How energy moves
- Where energy goes

• How energy changes/transfers

Use only the images you think are important and that you understand.

As many students arrived at this step, they did not understand how to label arrows or that they could actually label the arrows. Many students just used the same yellow arrow which was supposed to represent solar energy for all arrow selections. The greater difficulties came in the post test version when the students had a more robust understanding of concepts and began to make larger more detailed concept maps which the software did not save and it limited student input. After numerous frustrations and complaints students began to skip this question altogether. Even very high achieving students struggled to represent accurate content ideals using this tool.

Both students in this group (see figure 7) earned above 85% on the post test however their diagram depicts basic alternate conceptions which, if truly representative of their understanding, would negatively impact their content understanding.



Figure 6. "My System" response- high achieving group

The students did not use the arrow for heat or low albedo in their diagram. For the information they did provide, solar radiation is leaving the Earth in two instances. Infrared radiation is not being emitted from the Earth to the greenhouse gases, only to space. Based on their pre/post test assessment, this particular measure does not accurately demonstrate students understanding of the greenhouse effect.

The quality of the videos that were made aboard the JOIDES Resolution was inconsistent. During review of the scientific videos, statements by students in the WISE curriculum demonstrated numerous frustrations around the video entitled "Resolution of Models". Bianca wrote, "I watched twice and had no idea of what they are saying, something about resolution of models but I don't know what that means." Angie wrote, "I scrolled through the video 3 times trying to understand resolution of models, at 45 seconds to one minute and six seconds it says more and more resolution can let you see more differences in models I think, but I don't know what that means". However other students did watch the "Resolution of Models" video and could relate it to their prior knowledge as evident in the vignette by Saad, "Higher resolution, bigger space, the pixels and level of detail provides a higher quality picture, I hate when video games are pixilated." Another group used the idea of higher quality but connected it to simulations after watching the video twice they stated, "Higher and higher resolution of models, you can see the difference. Resolution normally has to do with quality so it has to do with the quality of how good the simulation is." Further research is needed on this specific video to see what further scaffolding is needed, if the vocabulary stated by the scientists is too difficult or if the resolution of modeling concept is too abstract for the students to comprehend in middle school.

6.3. Implications

Use of the curriculum provided statistically significant learning as measured by the pre/post tests. Students in both groups improved their understanding on content and NOS constructs. By allowing students to explain their thought processes while using the JING "Extreme Testing" simulation, more robust understanding and an avenue for student explanations was established. This can be easily replicated by teachers and researchers in future curriculums where there are student manipulated simulations. Also easily replicable in other settings are the authentic scientist videos where students watched and listened to real scientist talking informally about modeling. Videos like this do not currently exist in many curriculums, most videos include actors which students feel are not as authentic. Since these low budget films are easy to tailor to curricular needs and were proven effective in certain areas, more videos should be produced. In order to strengthen the aforementioned curricular successes, some modifications are necessary. Students did not refer to video titles or keywords during the lessons. In one instance, knowing the title of the video would have been sufficient to correctly answer questions. As the teacher-researcher walked around to each group, observations suggest that students just hit play as soon as they see the triangle without reading the introduction screen on the video or the top title bar. This aspect of the curriculum was not specifically tested in this iteration, however it may lead to a video where the scientist states the title of the video or after playing for a few seconds, the video title page and intro will pop back up to help students adhere to it.

This may be significant because during analysis of the video treatment students, some stated they skipped the videos because they thought they were all the same. Since the scientists were seated in the same locations, wearing the same clothing, and talking about the same topic Jemilia said "I stopped listening, I thought it was all redundant". This leads to a recommendation of having the scientist videos more varied for the visually acute middle school students.

When asked to describe the content. Bari stated, "Guy is doing dust and girl is doing atmosphere." Rachel stated, "I had trouble hearing", and then after watching a second time she added, "Their jobs are similar." The students watched the videos at least twice and sometimes three or four times in order to gather meaning. It was difficult to understand why some students needed to watch the videos so many times in order to gather meaning while other students did not. If this was a hearing issue, then one recommendation could be to provide a quieter environment or head phones for student usage. The more worrisome issue is that due to the technology infused school where students have iPads daily in this school, teachers create lessons or provide videos for students to watch repeatedly, and now many students are accustomed to viewing videos multiple times at their own pace in order to understand what is being said. These observations are based on this study setting, but perhaps could lead to pedagogical concerns for future lessons involving short videos as a teaching and learning tool.

Another recommendation to ensure students understand how models can function as scientific tools is to provide more instructions for the model drawing tool and be cognizant of struggling students who may need more scaffolding than the inquiry-based simulation provides. Xavia, a struggling reader, states how directions are easier to hear and once she understands what is being asked of her from oral directions, she can begin to analyze. She becomes successful and for one of the few times in class is excited about learning due to the combination of simulation making concepts visual and accessible to her while having tasks chunked and read together.

Xavia: How do I make this ghetto simulation work?

Teacher: What do you mean? Do you want to slow it down?

(Teacher shows her how to slow it down)

Xavia: What are the purple things?

Teacher: It says it right here on the top of the screen.

Xavia: It is easier to hear.

Teacher: Ok, they are showing the heat leaving Earth.

Xavia: I actually get it for the first time.

Teacher: What do you mean you get it for the first time?

Xavia: The farm absorbs or whatever, the ice doesn't absorb, it just bounces off. The ocean absorbs and makes heat with whatever but like before I only looked at the simulation triangles I did get what it was representing. I understand now the purple is the heat coming out of the Earth, the red is the heat inside the Earth. Yellow is the sunlight.

(When the teacher pushes further she makes a conjecture which later she tests.)

Teacher: Which land surface makes it hottest?

Xavia: Farm or grassy area because when you go by the ocean you feel colder, but if you normally stand in the middle of the field you warmer. I'm not sure why, maybe because the ocean has depth.

The personal feelings of students impede their thought process and need to be

taken into account by teachers and researchers. Many students were overheard making comments about the scientists' outfits or the order in which the scientists spoke, which evoked negative attitudes towards the curriculum. Cindy was overheard stating, "You mean the videos are different? I thought they were all the same since it was the same people, in the same outfits, sitting in the same spots." This vignette provides evidence that it is necessary to have variations in the videos with a movement of actors/scientists who wear different outfits during the discussion. Some of the female students were frustrated that it seemed as though Patti always spoke second. They would have liked her to take a more leadership role in the discussion regarding simulations. Another recommendation is to switch which scientist speaks first.

6.4. Future Research

Now that success for scientist videos has been established, higher quality videos need to be produced in order for greater student comprehension. Videos that include various scientists with diverse backgrounds in multiple settings should provide an increase in student interest while having them realize the diverse modeling techniques across all fields of science. Allowing scientists to demonstrate actual simulations while explaining their scientific thought process may provide greater student success. Focusing on areas of NOS weakness established by this research, specifically the creative and replicable aspect of modeling and simulations should be part of future curriculum creation.

Further research should include the students' evaluation of the accuracy of the simulation once they use the simulation to demonstrate causes of hot or cold climate. Using the newest simulations or having the students build their own simulations with the vast array of educational tools would provide greater instruction and a larger window into how the students think scientists actually build the models and simulations as opposed to their use of the simulations. Explicit questioning around the accuracy of the simulation's depiction of real life may reveal students' thoughts about limitation and strengths of models and simulations. This was not coded for in this research, or specifically asked about, but could be easily assessed in future uses of the same curriculum.

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Appendix A

Pre/Post Test

DO NOT WRITE ON THIS PAPER-ALL ANSWERS SHOULD BE BUBBLED ON ANSWER SHEET Science 2012

MULTIPLE CHOICE. Choose the one alternative that best completes the statement or answers the question.

For the even questions- put your level of confidence that you choose the best answer to the previous question.

1) Earth's energy emitted from the surface to space consists mainly of _____.

A) gamma rays

B) shortwave radiation

C) ultraviolet radiation

D) infrared radiation

2) Confidence level of question 1-A) 100% B) 75% C) 50% D) 25%

3) For the most part the atmosphere is heated directly from the _____.

A) storms

B) Sun

C) cyclones

D) Earth's surface

4) Confidence level of question 3-A) 100% B) 75% C) 50% D) 25%

5) The absorption of infrared radiation in the atmosphere is popularly called_____.

A) Coriolis effect.

B) the greenhouse effect.

C) advection.

D) scattering.

6) Confidence level of question 5-A) 100% B) 75% C) 50% D) 25%

7) With respect to absorption of solar radiation, it is understood that objects of ______ are the most efficient absorbers.

A) dark color B) snow C) light color D) stone

8) Confidence level of question 7-A) 100% B) 75% C) 50% D) 25%

9) The atmosphere is heated, for the most part, from _____.

A) the stratosphere

B) the thermosphere

C) below

D) above

10) Confidence level of question 9-

- A) 100% B) 75% C) 50% D) 25%
- 11) In terms of long-term temperature increases in the atmosphere, which of the following is TRUE?
 - A) Increases in greenhouse gases have been observed.
 - B) No changes have been observed in the 21st century.
 - C) Average global temperature has risen 5.0°C in the last 100 years.
 - D) It appears that we can readily curb the Carbon Dioxide problem.
 - 12) Confidence level of question 11-A) 100% B) 75% C) 50% D) 25%
- 13) The current observed increase in greenhouse gases in the atmosphere is attributable to______.
 - A) Earthquakes.
 - B) the end of the "Ice Age".
 - C) volcanoes.
 - D) human activities.
 - 14) Confidence level of question 13-A) 100% B) 75% C) 50% D) 25%
- 15) The main culprit for global warming appears to be_____
 - A) inaccurate computer models.
 - B) Carbon Dioxide.
 - C) chlorofluorocarbons.
 - D) nitrous oxides.
 - 16) Confidence level of question 15-A) 100% B) 75% C) 50% D) 25%
- 17) Methane is one of the "greenhouse gases". ______ is (are) a primary source of release of methane into the atmosphere.
 - A) The burning of coal at power plants
 - B) Automobiles
 - C) Grazing and Digesting animals
 - D) The use of aerosol sprays
 - 18) Confidence level of question 17-A) 100% B) 75% C) 50% D) 25%

19) Albedo is energy ______ from an object as compared to the original amount of energy that hit the object.

A) reflected	B) convected	C) conducted	D) absorbed		
20) Confidence A) 100%	level of question B) 75% C) 50%	19- D) 25%			
21) Simulations and	models are				
A) systematic	B) creative	C) data driven	D) all of the above		
22) Confidence level of question 21- A) 100% B) 75% C) 50% D) 25%					

23) Models and simulations can have limitations such as _____.

A) creativity B) the accuracy of the data being inputted C) computing of data D) cost compared to field work

- 24) Confidence level of question 23-
 - A) 100% B) 75% C) 50% D) 25%

25) In what ways can a model or simulation be different from the thing it represents?

- A) A model can be a different shape than the thing it represents, and it can be a different color.
- B) A model can be different shape than the thing it represents, but it must be the same color.
- C) A model can be a different color than the thing it represents, but it must be the same shape.
- D) A model must be the same shape as the thing it represents, and it must be the same color.

26) Confidence level of question 25-

- A) 100% B) 75% C) 50% D) 25%
- 27) A student wants to make a simple model of the solar system to help him compare how long it would take for a spaceship to travel between different planets. Which of the following things is essential for him to do in order to think about how long it would take?
 - A) He must make sure that the model of each planet looks like the planet it represents, but he does not need to accurately represent the relative distances between the planets because the most important thing is that models look like the thing they are modeling.
 - B) He must accurately represent the relative distances between the planets, but he does not need to make sure that the model of each planet looks like the planet it represents because only the relevant aspects of the thing being modeled need to be modeled accurately.
 - C) He must accurately represent the relative distances between the planets and also make sure that the model of each planet looks like the planet it represents, because a model should be as much like the thing being modeled as possible.
 - D) He does not need to accurately represent the relative distances between the planets and he does not need to make sure that the model of each planet looks like the planet it represents, because there are always some differences between a model and the thing being modeled.
 - 28) Confidence level of question 27-
 - A) 100% B) 75% C) 50% D) 25%

29) Which of the following could be represented with a simulation?

- A) An object, but not a process
- B) A process, but not an object
- C) Both an object and a process
- D) Neither an object nor a process

30) Confidence level of question 29-

A) 100% B) 75% C) 50% D) 25%

31) An architect is designing a house and shows the plans to his coworker. The coworker likes the design but tells the architect that he now needs to make a three-dimensional (3-D) model of the house before the construction company can begin building it.

The architect says that even though the plans are just drawings on paper, they can be thought of as a model of the house. The coworker disagrees and says that a model of a house has to be three-dimensional.

As they discuss it further, they agree that the plans have all the information the construction company will need to build the house, including designs for building the floors and walls, but the architect and his coworker still disagree about whether the plans can be called a model.

Which of them is correct and why? _____

- A) The architect is correct because he is the one who made the plans and therefore knows whether they can be considered a model.
- B) The architect is correct because the plans represent the features of the house that are to be built.
- C) The coworker is correct because a model needs to be three-dimensional.
- D) Neither is correct because the house has not yet been built, and there cannot be a model of something that does not exist.
- 32) Confidence level of question 31-A) 100% B) 75% C) 50% D) 25%
- 33) An engineer made a simulation of a ship to help him think about how it works. He made sure that some characteristics of the ship were accurately represented, but he did not include all of the ship's characteristics in his model. Is it okay that he ignored some of the ship's characteristics?
 - A) It is okay, but only if he represented the characteristics that affect how the ship works, because models need to include the characteristics that are relevant to what is being studied.
 - B) It is okay, but only if he represented the characteristics that affected whether the model looks like the ship, because models should look like the things that they represent.
 - C) It is okay, but only if he represented the characteristics that people would be interested in knowing about, because models are only used to communicate information to others.
 - D) It is not okay that he ignored some of the ship's characteristics. A model should be like the object it is representing in every way possible.

34) Confidence level of question 33-

- A) 100% B) 75% C) 50% D) 25%
- 35) Are simulations and models scientific tools?

A) sometimes B) always C) never D) depends on if they were made by a scientist

36) Confidence level of question 37-

A) 100% B) 75% C) 50% D) 25%

Appendix B

Answers to Pre/Post Test

1) d 3) d 5) b 7) a 9) c 11) a 13) d 15) b 17) c 19) a 21) d 23) b 25) a 27) b 29) c 31) b 33) a 35) b

Appendix C

Pre/Post Interview Questions

- 1. What do you think about when you hear the term "Greenhouse effect?"
- 2. What do you think causes the greenhouse effect?
- 3. Is it completely due to human activities?
 - i. What kind of human activities? Can you name some of them?
 - ii. If students try to connect ozone layer depletion as one of the causes of greenhouse effect, ask why they think so.
- 4. What are the consequences of greenhouse effect on human beings and on the planet Earth? (If they think it is a problem, ask for more information)
- 5. How can we reduce the greenhouse effect?
- 6. Science textbooks often represent the atom as a central nucleus composed of positively charged particles (protons) and neutral particles (neutrons) with negatively charged particles (electrons) orbiting the nucleus. How certain are scientists about the structure of the atom? What specific evidence do you think scientists used to determine the structure of the atom? Question from Khalid (1999).
- 7. What is a model?
- 8. How do scientists use simulations? What aspects of science are they beneficial for?
- 9. How would a scientist gather information about climate change?
- 10. How would you as a student gather information about climate change?
- 11. What, in your view, is science? What makes science (or a scientific discipline such as physics, biology, etc.) different from other disciplines of inquiry (e.g., religion, philosophy)?
- 12. What is an experiment?
- 13. Does the development of scientific knowledge require experiments? Question from Khalid (1999).

If yes, explain why. Give an example to defend your position.

If no, explain why. Give an example to defend your position.

- 14. In the recent past, astronomers differed greatly in their predictions of the ultimate fate of the universe. Some astronomers believed that the universe is expanding while others believed that it is shrinking, still others believed that the universe is in a static state without any expansion or shrinkage. How were these different conclusions possible if the astronomers were all looking at the same experiments and data?
- 15. (By posing a scientific controversy and stressing the fact that scientists are using the same data but coming up with differing explanations, this question invites respondents to think about factors that affect scientists' work. The factors range from scientists' personal preferences and biases to differing theoretical commitments to social and cultural factors.) (This question aims to assess understandings of the role of human inference and creativity in science, the role of models in science, and the notion that scientific models are not copies of reality.) Question from Khalid (1999).

- 16. Have students use simulation for "Extreme Testing", explain infrared, radiation, why C02 or greenhouse gases affect temp, how come simulations respond that way?
- 17. Show JING videos, ask them why they manipulated the simulation that way.

Appendix D

Embedded WISE Questions

On a COLD day, Akbar walks to his car, parked in the sun. When he gets into his car he is surprised by the temperature inside the car, which had NOT been driven for a week. What do you think Akbar noticed?

1. The temperature of the air inside the car was:

• Colder than the outside air

• Warmer than the outside air

Exactly the same as the outside air

2. Which of the following ENERGY SOURCES affected the temperature of the air in the car the most?

C The Sun

С

С

O

The car's engine

The gasoline in the gas tank.

C The Earth's core

No energy sources.

3. Explain your answers.

You have not learned about this yet, so JUST TAKE YOUR BEST GUESS.

1. Burning coal to produce electricity has increased the amount of Carbon Dioxide in the atmosphere. What possible effect could the increased amount of Carbon Dioxide have on our planet?

• A warmer climate

A cooler climate

C

C

Lower relative humidity

More ozone in the atmosphere

Gwen is concerned about her energy use. She'd like to make changes to lower her energy use.

1. Which ONE of the following would help the most?

Walk to school instead of riding in a car

• Turn off computer and lights when not in use

• Eat less meat

C

- Stop littering
- 2. Which ONE of the following would help the LEAST?
- Walk to school instead of riding in a car
- Turn off computer and lights when not in use
 - Eat less meat

C

С

Stop littering

Gwen told her teacher about a winter day that was very warm. Gwen thought it was evidence that the global climate is getting warmer.

- 1. What do you think her teacher said?
- Temperature doesn't change much, but wind chill or humidity can make it SEEM warmer or colder.
- Global warming is not true, otherwise there would be no snow.
- One day is not enough evidence to show a change in global climate.
- 2. Explain your answer.

1. Has global temperature in the past always been the same as it is today?

In the past:

It was ALWAYS THE SAME temperature as today

C It was ALWAYS MUCH COLDER than today

^C It was ALWAYS MUCH WARMER than today

It was BOTH COLDER AND WARMER than today

2.6

Revise your answer based on what you just learned.

1. Gwen told her teacher about a winter day that was very warm. Gwen thought it was evidence that the global climate is getting warmer.

What do you think her teacher said?

Temperature doesn't change much, but wind chill or humidity can make it SEEM warmer or colder.

Global warming is not true, otherwise there would be no snow.

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One day is not enough evidence to show a change in global climate.

2. Explain your answer.

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3.1

Before you explore, tell us what you think happens! Make your best guess.

1. What kind of energy from the Sun reaches the Earth?

C Light (electromagnetic waves)

Heat

Both light and heat

2. What happens to energy from the Sun when it reaches the Earth?

All of the energy gets reflected by the Earth's surface

All of the energy gets absorbed by the Earth's surface

Some gets reflected and some gets absorbed by the Earth's surface

3.2

3 An architect is designing a house and shows the plans to his coworker. The coworker likes the design but tells the architect that he now needs to make a three-dimensional (3-D) model of the house before the construction company can begin building it.

The architect says that even though the plans are just drawings on paper, they can be thought of as a model of the house. The coworker disagrees and says that a model of a house has to be three-dimensional.

As they discuss it further, they agree that the plans have all the information the construction company will need to build the house, including designs for building the floors and walls, but the architect and his coworker still disagree about whether the plans can be called a model.

Which of them is correct and why?

- E) The architect is correct because he is the one who made the plans and therefore knows whether they can be considered a model.
- F) The architect is correct because the plans represent the features of the house that are to be built.
- G) The coworker is correct because a model needs to be three-dimensional.
- H) Neither is correct because the house has not yet been built, and there cannot be a model of something that does not exist.

3.5

Which of the following could be represented with a model?

- E) An object, but not a process
- F) A process, but not an object
- G) Both an object and a process
- H) Neither an object nor a process

5. In order to predict the weather, weather persons collect different types of information.

Often they produce computer models of different weather patterns.

(a) Do you think weather persons are certain (sure) about the weather patterns?

(b) Why or why not?

6. What do you think a scientific model is?

7. Scientists try to find answers to their questions by doing investigations / experiments. Do

you think that scientists use their imagination & creativity in their investigations /

experiments? YES NO

a. If NO, explain why.

b. If YES, in what part of their investigations (planning, experimenting, making observations,

analyzing data, interpretation, reporting results, etc.) do you think they use their imagination

and creativity? Give examples if you can.

1.10 & 10.10

Build a "My System" model to explain to Gwen how the Earth is warmed by energy.

Be sure to include the following information as you LABEL ALL ARROWS:

- Where energy comes from
- How energy moves
- Where energy goes
- How energy changes/transfers

Use only the images you think are important and that you understand.



Appendix E

Location and descriptions on WISE for Embedded Scientist Videos of Video Group

Section: 1.10

Amount of time: 0:53 <u>http://www.youtube.com/watch?feature=player_embedded&v=RIsR0BjZm0A</u>

Title: Introduction

Scientists use simulations and virtual models in their scientific work. Throughout this WISE project you will learn a bit about how Steve and Patti use simulations in their scientific research. Lets meet them now!!

In the next step you are going to build a stagnate or non moving model of how energy flows through the atmosphere. Below are directions for you to create a path for energy to follow!

Show Gwen how the Earth is warmed by energy.

Be sure to include the following information as you LABEL ALL ARROWS:

- Where energy comes from
- How energy moves
- Where energy goes
- How energy changes/tranforms

Section: 3.4 Amount of time: 5:57 <u>http://www.youtube.com/watch?feature=player_embedded&v=zExRvlaLZbU</u> Title: Scientists Make Models

- Scientists build models or simulations to show the interaction of variables.
- Previously you built a model in step 1.8 based on how you think energy travels through the atmosphere.

Scientists can take those models based on real world data and make them into virtual environments that take into account many variables at once and their interactions. Sometimes these are called virtual models, simulations or visualizations. Below is a video of scientist discussing what simulations are and how they have changed over time.

Section: 3.5

Amount of time: 1:12 <u>http://www.youtube.com/watch?feature=player_embedded&v=qUYK26unOP8</u> Title: Creativity of modeling

How have virtual models or simulations changed over time according to the video? In the top center of your screen is a light bulb where you can add ideas. Add three separate ideas about how simulations have changed over time. Tag these ideas source as movie/video.

Here is a video of Patti explaining to Steve how she feels models/simulations are creative and they are made with inputs and outputs. One of her favorite aspects of simulations is that they are **representative systems of nature that can be used over and over again**. It is normally cheap and efficient to run a simulation on a computer compared to doing the same thing in the real world. Watch and then answer the questions below.

Which of the following could be represented with a model?

An object, but not a process

• A process, but not an object

Both an object and a process

• Neither an object nor a process

Section: 3.6 Amount of Time: 1:06 <u>http://www.youtube.com/watch?feature=player_embedded&v=F-MUcGE40I4</u>

Title: Examine the Various Variables in a Simulation

Below is a simulation which has lower resolution and some major components of the greenhouse effect model were removed. This was done to simplify the model yet still provide educational information to you. According to Steve how can the specific aspects of a model change and what are the benefits of simplifying the model?

Click the "Run" button to start or stop the model.

Use the "Model Speed" slider to change how fast it runs.

You can adjust any variables you would like over the next five minutes to become more familiar with how the simulation works and how the variables impact each other and the graph.

AFTER 5 minutes...ADD at least 3 observations you made during the simulation run to your add ideas tab. (top center of screen, light bulb) Tag these new observations as "Visualization or Model". You can continually add notes here and they will be saved for later use in the project.

Section: 4.3 Amount of Time: 1.06 http://www.youtube.com/watch?feature=player_embedded&v=C3uZKxQv8qk Title: How scientists use models

In the previous step you made a prediction about the LOW albedo. How do scientists make predictions for the future?

- Simulations are made on computers
- Scientists guess and check until they think they are correct
- Scientists use the models of the past to predict how the future will work

Section: 5.2 Amount of Time: 1:13 <u>http://www.youtube.com/watch?feature=player_embedded&v=XwGtzzOorv8</u> Title: Limitations of Modeling

Simulations and Models are used as predictive tools but do have limitations. Watch below to hear the discussion about potential model limitations.

Go up to your light bulb and add 4-7 limitations of models. They can be from the video, from the simulations in this WISE project or any other limitation ideas. Tag your limitation ideas with a source that accurately explains where that idea came from.

After you added to your ideas---Answer this question below-

How do you think greenhouse gases are involved with global temperature and energy? Make your best scientific guess!

1. If there are more greenhouse gases in the atmosphere, what do you predict will happen to the global temperature?

• It will increase

- It will decrease
- It will stay the same

Appendix F

Coding scheme and example

CONTENT	Example
Radiation comes in from the sun/solar radiation	"When I hear the term Greenhouse effect I think about thermal radiation on Earthfrom sun." Steven "Solar radiation enters Earth atmosphere and enters Earth's crust. It then forms into heat. As it continues to heat Earth, it then comes back out as infrared radiation" Taylor
Solar radiation turns to heat energy	"The red dots (inside Earth) are just the heat formed inside Earth from solar energy that gets absorbed by Earth and some is released as infrared" Ayana
Infrared energy is trapped by greenhouse gases	"Infrared Radiation effects the model by cooling the Earth when it exits or heating when it stays. Carbon Dioxide and other greenhouse gases effect the temperature by trapping infrared rays in the Earth. Albedo effects the world temperature by ether reflecting sun rays or absorbing them." Jaelen
Greenhouse as physical objects-not related to actual Earth greenhouse effect	"When I hear the words green house effect I think of warmth and the photosynthesis. It's the little house where flowers are planted and they absorb heat" Augosto
Thought of greenhouse effect in terms of good/bad	"The greenhouse effect is bad, it makes the world super hot" Quinton or "The greenhouse effect is good, without the world would be too cold for life" Jazzir
Greenhouse effect=climate change/global warming	"The greenhouse effect changes climates over time. It can cause the Earth to either heat up a few degrees or become colder. Depending on where you live either one can cause a

	big impact. Think of the polar bears a few degrees increase and the land they live on is shrinking moment by moment" Kytson
Pollution	"I think that pollution in the air causes infrared rays to stay in the atmosphere and heat the Earth" Joel
Albedo	"They are both being reflected on ice, it means like having a mirror and they are being reflected back" Rachel

SIMULATIONS	Example
Model Object	"Freedom tower had little 3d models at a bigger scale for an actual object, this school came to be from the models made for it." Lela
Model Process	"Simulations show interactions to represent process" Klyvert
Model process & Object	"A model is a demonstration of what event would occur on a certain process or object" Ashwin
Systemic	"Scientists use simulations to present their explanation or even examine new things. Simulations can be beneficial for any type of cycles or movement of something." N'Digo
Used as scientific tasks	"The temp is increasing because the amount of sun rays coming out of the Earth is greater than the infrared radiation being trapped by the greenhouse gases. If you would add clouds, then you could test some of the sun rays would" Ahmed
Replicable	"Scientist uses simulations to test different outcomes in the same situations. They're useful because instead of building many models to test the same thing they can use the same simulation over and over." Xavier
Predictive	"Inputting data and understanding it to compare it to data of the past and to understand current and future data" Desiree
Creative	"Even though all scientists use the same data, they use some
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	imagination to come to conclusions" Kara