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Assessing the potential benefits of learning about environmental issues through a systems thinking pedagogy

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Assessing the Potential Benefits of Learning about Environmental Issues through a Systems Thinking Pedagogy

A dissertation presented in part fulfillment of the requirements for the Degree of Master of Science in Sustainable Environmental Resources Management/Master of Science in Integrated Science and Technology

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ABSTRACT

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ASSESSING THE POTENTIAL BENEFITS OF LEARING ABOUT ENVIRONMENTAL ISSUES THROUGH A SYSTEMS THINKING PEDAGOGY

Systems thinking is a fundamental learning methodology in sustainability education and in some K-12 standards-based education systems in the United States. However, there is little research and practical application on the use of systems thinking in environmental education, especially at the elementary level. This thesis uses a case study on climate change to assess whether a pedagogy based on systems thinking can fulfill learning objectives derived from the Illinois Learning Standards for Science (ILSS) and provide further insights and understandings on the subject being studied. Three learning modules on climate change consisting of systems thinking habits of mind, concepts, and tools were taught to fourth grade students from the Chicago area as an informal pilot study. It was determined that a systems thinking approach does yield results that suggest fulfillment of the ILSS. A systems thinking approach is also successful in engaging students, creating a fun and interactive learning environment, and making learning more learner-centered and hands-on. More empirical research on the benefits of systems thinking, especially in elementary education, is needed, in both standards-based education and in environmental education.

KEYWORDS

SYSTEMS THINKING; ENVIRONMENTAL EDUCATION; ELEMENTARY EDUCATION; CLIMATE CHANGE

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CHAPTER 1 – THE CASE FOR LEARNING ABOUT ENVIRONMENTAL ISSUES THROUGH A SYSTEMS THINKING PERSPECTIVE

This thesis offers systems-thinking based lessons on environmental issues for fourth grade students and describes a pilot test. Fourth grade students were chosen at the target population for the learning modules. This capitalized on the author's previous experience teaching this age-group. Students from St. Luke Parish School, a K-8 Catholic Archdiocese of Chicago school located in a suburb about 10-15 miles from the City of Chicago, participated in the testing of the learning modules. These students were introduced to climate change and to the consequential environmental issues facing Lake Michigan through a pedagogy based on systems thinking. The climate change case study is presented as learning modules, which are to be used by any educator that addresses climate change, whether it be in the classroom or in an information education environment.

Education is vital for improving society's ability to understand and address environmental issues, particularly education that focuses on issues from a local perspective (United Nations Programme of Action, 1992). Hence, there is a need to improve environmental education materials and strategies (Hudson, 2001; Karlsson, 2000). However, there has been little focus on elementary education or on the use of systems thinking as a teaching and learning strategy. Furthermore, there are very few studies that evaluate the impact of systems thinking methods on students' understanding of environmental issues. Although systems thinking materials are available for grades K-12, more single- and interdisciplinary systems thinking concepts and tools are needed (The Creative Learning Exchange, 2002). These materials should be appropriate to the discipline area and existing curriculum topics (Costello, et al., 2001; Lyneis & Stuntz, 1994).

This thesis takes a case study approach focusing on issues relevant to the environment of Lake Michigan. Selected sections of the Illinois Learning Standards for Science (Illinois State Board of Education, 2002) were used as a starting point for defining the learning objectives of the learning modules of the case study. In addition, the learning modules and their assessments were designed to evaluate the potential benefits of a systems thinking approach to environmental education. The questions addressed in the study are:

1. What evidence can an informal pilot learning experience provide that a systems thinking pedagogy will achieve selected learning objectives within the Illinois Learning Standards for Science (ILSS)?
2. Does the use of a systems thinking pedagogy provide insights and understanding in fourth grade students that would not be achieved otherwise?

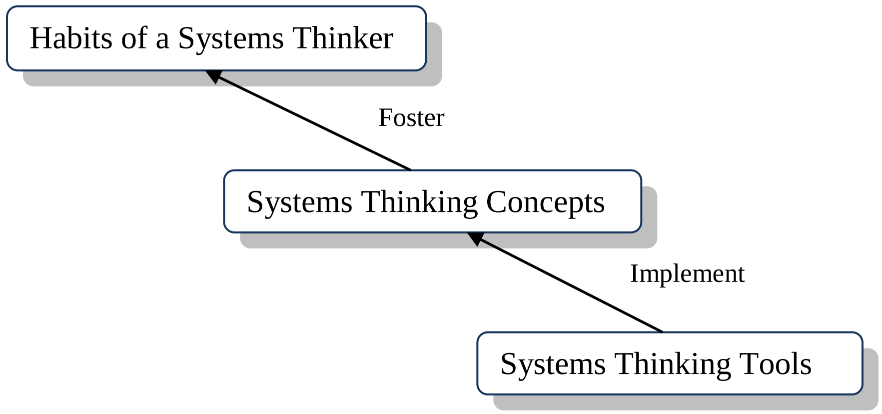
This chapter presents the case for using systems thinking in teaching to K-12 students about environmental issues. Current attention to systems thinking in the learning standards of public school systems and in sustainability education is discussed, along with evidence for the benefits of learning through systems thinking. Chapter 1 concludes with how systems thinking can be applied to teach about environmental issues. Chapter 2 discusses the habits of a systems thinker, concepts, and tools of systems thinking that were used in the case study, explaining why they are relevant and useful. A description of the module content is also presented in Chapter 2. Chapter 3 includes the methods for the creation of the learning modules and for the pilot study in which the modules were implemented with a group of fourth graders. Chapter 4 consists of the results from the pilot effort, along with discussion and reflection on the potential for systems thinking in elementary school environmental education.

Systems Thinking Defined

A system is “a group of interacting, interrelated, and interdependent components that form a complex and unified whole” (Pegasus Communications, Inc, 2000-2004). Systems thinking, according to Forrester (1994), “…is about systems, talking about the characteristics of the systems, acknowledging that systems are important, discussing some of the insights from system archetypes, and relating the experiences people have with systems.” Pegasus Communications, Inc, a leading provider of systems thinking resources, defines systems thinking as “a way of understanding reality that emphasizes the relationships among a system’s parts, rather than the parts themselves” (Pegasus Communications, Inc, 2000-2004). Systems thinking allows us to see the whole picture, to discover patterns instead of isolated facts, and to investigate interdependencies among system parts (Lyneis, 1995). In doing so, we see a more complete picture of reality (Pegasus Communications, Inc, 2000-2004).

The Waters Foundation, a leader in systems thinking educating, training, and research, has a vision “to deliver academic and lifetime benefits to students through the effective application of systems thinking concepts, habits and tools…” (Waters Foundation, 2010h). The Waters Foundation identifies a systems thinker as one who has internalized the habits of a systems thinker (“habits”) (Waters Foundation, 2010k). These “habits” will be discussed at the end of this chapter, along with their relevance to environmental and elementary education. By “habits” we refer to those practices and ways of viewing problems that characterize systems thinking. Supporting these “habits” are the concepts and tools of systems thinking (Waters Foundation, 2010k). The relationship among these elements is illustrated in Figure 1. “Concepts” refer to those foundational ideas and principles of systems that provide insights into systems – how they are structured, and how they work. The tools enable the communication of one’s understanding of a system’s structure and behavior through graphic illustrations (Pegasus Communications, Inc, 2000-2004). They also enable one to visualize dynamic complexity (Waters Foundation, 2010l). Systems thinking concepts and tools used in the case study are discussed in Chapter 2.

Figure 1. A hierarchical organization of the habits, concepts, and tools employed by a systems thinker.



The Application of Systems Thinking in K-12 Standards-Based Education and in Sustainability Education

The overall question is, with all the different educational methods available, why use a systems thinking approach to environmental education for children? Sterman (2000) states,

> "Effective decision making and learning in a world of growing dynamic complexity requires us to become systems thinkers – to expand the boundaries of our mental models and develop tools to understand how the structure of complex systems creates their behavior."

In other words, in order to better prepare young people to appropriately respond to problems like global climate change, they must be trained in the habits of mind associated with systems thinking.

In addition, systems thinking fits nicely with the different ways that children learn – visual, auditory, and kinesthetic (Regional Support Center, n.d.b). According to Lyneis (1995), "Young children are intuitively good systems thinkers, probably because their learning has not become so fractured yet." Systems thinking is an academic learning requirement in Washington State's K-12 Science Standards, and is being taught in some school systems in the United States, including Waters Foundation supported Portland

Public Schools and several schools in and around Tucson, Arizona. Yet, it has not been addressed in the Illinois Learning Standards for Science.

Although systems thinking has yet to make a big impact on environmental education, it is increasingly recognized as an important characteristic of effective sustainability education (Center for Ecoliteracy, 2004-2010; Frederico, Cloud, Byrne, & Wheeler, 2003; Goldman, 1999). According to The Belgrade Charter: A Framework for Environmental Education (UNESCO-UNEP, 1976), the goal of environmental education is,

> "To develop a world population that is aware of, and concerned about, the environment and its associated problems, and which as the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions to current problems, and the prevention of new ones."

"Sustainability education," as defined by the Tahoe Center for a Sustainable future,

> "is a new way of looking at the environment in which students: examine the network of dependant relationships that exists between the environment, the economy and the culture; and come to understand that these interrelationships exists on the local, regional, national, and global levels" (Goldman, 1999).

Systems thinking allows us to think about and describe these interrelationships, patterns, and dynamics, as well as to look at the patterns that create the system (Sweeney, n.d.a). According to Cloud (2005),

> "One of the greatest opportunities that education for sustainability can offer to environmental education that will strengthen its capacity over the next ten years is the contribution of the tools, concepts, archetypes, and 'habits of mind' of systems thinking and system dynamics education – a core content area of education for sustainability."

Living systems contain systems nested within other systems (Capra, 1998). Living systems are everywhere, shaping and surrounding us (Sweeney, n.d.a), permeating our daily lives (Capra, 1998). As such, sustainability education cannot be taught without systems thinking and system dynamics (Cloud, 2005).

Systems Thinking in K-12 Standards-based Education: Public School Experiences and Their Uses of Systems Thinking

Systems thinking is part of the K-12 science methodology in a few school systems in the United States. Washington State is unique in that systems are emphasized in K-12 science standards (Washington State, 2009). Systems thinking is the first of four "Essential Academic Learning Requirements" (EALR 1), and is included because of its importance in "diverse and cutting-edge fields" such as: climate change, genetic engineering, and designing and troubleshooting complex technological systems (Washington State, 2009). A student in Grades 4-5, according to the Washington State K-12 Science Standards should be able to "analyze a system in terms of subsystem functions as well as inputs and outputs" (Washington Department of Public Instruction, 2009).

A number of schools in Tucson, Arizona and in the Portland Public School system are supported by the Waters Foundation to incorporate systems thinking into their curricula. Pima County Schools (Tucson) utilize systems thinking to achieve content standards and skills objectives while further enabling students to apply higher level thinking skills (Regional Support Center, n.d.a). Borton Primary Magnet School (Tucson) utilizes systems thinking as an instructional method. Tucson's Catalina Foothills School District (CFSD) is committed to "21st Century Learning," which requires students to gain skills in areas such as technology, teamwork, and systems thinking (Catalina Foothills School District, 2008b). Systems thinking is included as one of CFSD's 21st Century learning skills because it presents students with the ability to interpret the increasingly complex world in which they live (Catalina Foothills School District, 2008a). CFSD's K-12 Science Standards contain a "Systems Thinking Curriculum Strand."

CFSD incorporates systems thinking into their marine studies program (Catalina Foothills School District, 2007). Systems thinking enables the students in the program to understand how all systems interrelate and are impacted by other factors (Catalina Foothills School District, 2007). One of the experiments that incorporate systems thinking analyzes the effects on shrimp when food is changed over time (Catalina

Foothills School District, 2009). Through systems thinking, these students see how changing one aspect of a system can affect everything (Catalina Foothills School District, 2009). CFSD also incorporates systems thinking into lessons on groundwater, in which the students learn the relation between cause and effect through a groundwater simulation (Catalina Foothills School District, 2009). Through the simulation, the students can see that there is more than one way to look at and approach an answer to a problem (Catalina Foothills School District, 2009). The goal is that systems thinking practices inside the classroom will be applied in the students' lives outside of the classroom (Catalina Foothills School District, 2007).

The Systems Thinking in Schools Project by the Waters Foundation in Portland relies on an "infection model," in which teachers who have an interest in learning about systems are trained and supported by the Waters Foundation (T. Taber, personal communication, June 11, 2010). These K-12 teachers begin their instruction from a "habits" point of view and connect the "habits" to the tools (T. Taber, personal communication, July 7, 2010). Children are eased into the tools with children's books, such as the Lorax. (T. Taber, personal communication, July 7, 2010). The ultimate goal of the Portland program, according to Tim Taber, NW Coordinator for the Systems Thinking in Schools Project based in Portland, is for

> "…kids to understand they are a part of whatever system they are involved with and as such have an effect on the outcome of that system. Being equipped and able to use the tools, concepts, and habits of systems thinking, they will be better able to work within the system to identify were effective change is in order if the outcomes of the system need to be changed" (T. Taber, personal communication, June 30, 2010)

Portland Public Schools have teachers incorporating systems into the district curriculum with favorable results (T. Taber, personal communication, June 11, 2010). A 5th grade teacher at Winterhaven School uses systems thinking as a focus for problem solving across the curriculum. (T. Taber, personal communication, June 30, 2010). The latest project involves students looking at the concepts of permaculture (T. Taber, personal communication, June 30, 2010). Permaculture is a "nature-nature inspired design philosophy for creating permanent cultures by assuring…permanent, that is sustainable, agriculture" (Urban Harvest, n.d.).

Systems Thinking in Sustainability Education: Sustainability Education Organizations and Their Uses of Systems Thinking

Two organizations dedicated to sustainability education are The Cloud Institute and The Center for Ecoliteracy. Their applications of systems thinking are briefly discussed below.

The Cloud Institute, which provides K-12 school systems and their communities with the necessary content to educate for sustainability, defines education for sustainability as "a dynamic system of core content, competencies, and habits of mind coupled with a pedagogical system that is learner centered and inquiry based" (The Cloud Institute for Sustainability Education, 1995-2009a). The Cloud Institute has developed nine "Education for Sustainability Core Standards" that are a guide to achieving these standards (The Cloud Institute for Sustainability Education, 1995-2009b). Number three is "The Dynamics of Systems and Change." Through "The Dynamics of Systems and Change" students are to understand how systems change over time and be able to utilize systems thinking concepts and tools in their lives to make informed choices (The Cloud Institute for Sustainability Education, 1995-2009b).

The Center for Ecoliteracy, founded by physicist and systems thinker Fritjof Capra, integrates ecological principles and sustainability into school curricula. According to The Center for Ecoliteracy, a systems thinking approach is an essential part of learning about sustainability because "a systems approach helps young people understand the complexity of the world around them and encourages them to think in terms of relationships, connectedness, and context" (Center for Ecoliteracy, 2004-2010). Furthermore, a systems approach enables teaching material to be presented holistically, which is synonymous to life experiences (Center for Ecoliteracy, 2004-2010). The Center for Ecoliteracy presents six core ecological concepts for students to understand and apply to the real world. They are: networks, nested systems, cycles, flows, development, and dynamic balance (Center for Ecoliteracy, 2004-2010). As these six are central concepts of systems thinking, sustainability education through a systems thinking perspective is an obvious choice. Other sustainability education organizations that incorporate systems thinking are Learning for Sustainability (Learning for Sustainability, 2006-2010) and The Tahoe Center for a Sustainable Future (Tahoe Center for a Sustainable Future, 2000).

One example of the application of systems thinking in environmental education is the Wisconsin's Model Academic Standards for Environmental Education. These standards address five applications to encourage learning. The second application, the "Ability to Think," includes systems thinking. Under the section "Environmental Issue Investigation Skills," the standard states that students are to "be able to identify, investigate, and evaluate environmental problems and issues" (Wisconsin Department of Public Instruction, 1998). The rationale is that skills in environmental investigations "provide students with opportunities to apply and improve their capacity for systems thinking and their understanding of a sustainable world and society" (Wisconsin Department of Public Instruction, 1998).

Evidence on the Benefits of Learning through Systems Thinking

There are few empirical research studies on the benefits, or results, of learning through systems thinking, either in standards-based education or in other venues of environmental education. Most of the evidence is anecdotal, from teacher descriptions of observed learning outcomes (LaVigne, 2009). Teachers have expressed how students can better organize and communicate their thinking through learning through systems thinking (LaVigne, 2009). Linda Booth Sweeney claims that the evolution of systems thinking over the past 50 years has led to more effective learning (Sweeney, n.d.a). J.W. Forrester, who has made numerous contributions to the use of systems dynamics and K-12 education, believes that systems thinking allows students to more effectively interpret the world around them (Forrester, 1994). Using a systems thinking approach is shown to make the learning process more learner-centered, increase students' engagement and provide a more relevant experience (The Creative Learning Exchange, 2002). This has been demonstrated through the observations of students asking better questions, enthusiastically taking charge of their learning, and strengthening their problem-solving skills (The Creative Learning Exchange, 2002).

The Waters Foundation has been the leader in systems thinking research through five years of "Collaborative Action Research" funded by the Foundation. Collaborative Action Research is defined by Caro-Bruce (2000) as,

> "A process in which participants systematically examine their own educational proactive using the techniques of research, for the purpose of increasing learning of students, their teachers, and other interested parties" (as cited in, Waters Foundation, 2010a).

Specifically, the Waters Foundation provides a standard document template for each researcher, which includes the research question of interest, the instructional plan, the assessment techniques and results, and the conclusions and implementations for the future (Waters Foundation, 2010a). Over 300 individual reports have completed by The Waters Foundation Systems Thinking in Schools Network (T. Taber, personal communication, June 30, 2010). From the Collaborative Action Research program, the Waters Foundation has revealed that learning through systems thinking helps students make thinking visible, make connections, solve problems, develop reading and writing skills, and increase engagement (Waters Foundation, 2010b). Through use of these tools, students can clarify and visually represent their mental models of complex systems, explore their models, identify misconceptions, and illustrate their understandings of the connections and interdependencies of complex systems (Waters Foundation, 2010b). These visual tools also help students to make connections between the subject being studied and their everyday life experiences, while enabling them to discover how the various systems we encounter in life are not as different from one another as once thought (Waters Foundation, 2010b). Students are able to use systems thinking concepts and tools to solve problems with a different perspective, to question solutions to complex problems, and to understand their own mental models (Waters Foundation, 2010b). In addition to the understandings gained from teaching systems thinking, the Waters Foundation has identified some benefits of using system thinking pedagogical tools. Behavior over time graphs (BOTGs) have helped students describe changes over time, patterns, and trends (Waters Foundation, 2010b). Causal loop diagrams (CLDs) have aided students to identify a system's cause and effect connections and the resulting feedback relationships (Waters Foundation, 2010b). Each of these tools was used in the learning modules developed for this thesis and will be described in detail later.

The literature documents studies comparing students who have been exposed to systems thinking throughout their schooling to those who have not. Plate (2006) assessed the effectiveness of systems thinking on understanding complexity in social and ecological systems with middle school students and undergraduates. Through a cognitive mapping technique, the 2006 study revealed that systems-oriented instruction significantly improved the undergraduates' comprehension of a case study involving system complexity. Middle school students who explored the case study through systems thinking demonstrated a greater understanding than the control students. Plate (2010) showed that systems-oriented instruction allowed middle-school students to better understand information about dynamically complex social and ecological systems. Plate assessed students through a tool known as Cognitive Mapping Assessment of Systems Thinking (CMAST). CMAST evaluates students' abilities to understand complex systems through examining the mental models that students develop (Plate, 2010).

The Association of Systems Thinking and Environmental Education

Hudson (2001) notes "Environmental education programs must provide a continuum of experiences from online to hands-on." McDonnell (2001) also states that "hands-on and minds-on" activities yield high quality classroom experiences. Hudson (2001) further notes that the complexity of environmental issues must be expressed in an understandable and inviting manner, while giving science a central role in the explanation. Systems thinking tools can fulfill these needs. As previously noted, systems thinking tools are visual, interactive, and learner-centered. The concepts of systems thinking (described in detail in Chapter 2) are highly relevant to environmental issues and can be effectively taught through various hands-on, experiential educational games and exercises. These concepts can also be learned through interactive computer simulations, in which students observe how the behavior of the system emerges from the relationship of the system's constituent parts (Waters Foundation, 2010i). An example of an online system dynamics computer simulation game is "Fish Banks" (Meadows, 2010). Such simulations further enhance a visual and interactive experience, since predictions can be instantly tested and changes to the system can be seen immediately (Waters Foundation, 2010i). One can display the changing conditions of an ecosystem through a BOTG, making note of when the changes the occurred, and thus possibly making further inferences as to why those changes happened (Waters Foundation, 2010c). The relationships among the elements of the underlying system can be shown on a CLD or a connection circle. Interactions between the elements can be visualized, and feedback loops discovered. This can lead to a greater understanding of the system in consideration, or misconceptions can be cleared (Waters Foundation, 2010d). Activities can become more hands-on and interactive through human role-playing games – in which students assume the roles of particular elements of the system and act according to existing interdependencies with other elements

Systems thinking is not the only instructional method that incorporates activity-based and hands-on activities. What is unique about systems thinking is the habits of a systems thinker; these "habits" coincide with what environmental education recognizes as important elements of environmental literacy. Environmental literacy is defined by Disinger & Roth (1992) as "the capacity to perceive and interpret the relative health of environmental systems and take appropriate action to maintain, restore, or improve the health of those systems." Shifting one's focus from objects to relationships is an aspect of systems thinking that is fundamental to environmental literacy (Capra, 1998). This shift in focus is evident in the habits of a systems thinker. Furthermore, environmental literacy focuses on four "basic understandings," outlined in Table 1. The next section discusses the comparison between these "basic understandings" and the habits of a systems thinker.

Table 1. Basic understandings of environmental literacy as outlined by Disinger & Roth (1992)

Basic Understandings of Environmental Literacy
1. The interrelationships between natural and social systems 2. The unity of humankind with nature 3. Technology and the making of choices 4. The developmental learning throughout the human life cycle

The Habits of a Systems Thinker and Environmental Literacy

Systems thinking practitioners have attempted to address the habits of mind that characterize a systems thinker. The Waters Foundation and Linda Booth Sweeney have both outlined these "habits" – the Waters Foundation lists 13 "habits," while Sweeney lists 12 (Appendix 1, Tables 1 & 2). These "habits" are necessary to develop in order to "intentionally use systems principles to understand complexity of everyday situations and to design for desired futures" (Sweeney, n.d.b). Many of the "habits" coincide with a more mature audience, developed over years of learning through systems thinking. Table 2 is an attempt to synthesize these two lists into a group of "habits" that are appropriate to fourth graders understanding environmental issues.

Table 2. Habits of a systems thinker, reflecting both a fourth grade level and the understanding of environmental issues

Habits of a Young Systems Thinker
1. Sees the whole, or the big picture
2. Looks for connections among elements in a system
3. Describes how things accumulate or diminish over time (stock and flow dynamics)
4. Observes how elements within systems change over time, generating patterns and trends
5. Identifies the circular nature of complex cause and effect relationships
6. Sees self as part of the system

The “habits” in Table 2 are consistent with the goals of environmental literacy in Table 1. These “habits” describe someone who can identify relationships and connections in a system, which, as previously stated, is fundamental to environmental literacy. Someone who can *see himself as part of the system* (“habit” six) would better comprehend the *unity of humankind with nature* (“basic understandings” two). With the ability to interpret systems, to recognize systems’ complex relationships, and to perceive the big picture (“habits” one thru five), one may be better able to understand the *interrelationships that exist between natural and social systems* (“basic understandings” one), such as the relationships between human activities and climate change. Furthermore, Tim Taber suggests using “habits” as a problem solving strategy to approach environmental education (T. Taber, personal communication, July 7, 2010). The idea is to practice as many of the “habits” as possible in order to develop to develop awareness of the structure of the system, and thus be able to make a suggestion on how to change things (T. Taber, personal communication, July 7, 2010).

In reading and learning about the environment, ecosystems, and the interaction of humans with such, the words *interrelationship, connection, system, complexity,* and *behavior* cannot be ignored. Haury (2002) believes that we are unaware of our impact of nature because we have let our ecological connections slip from consciousness – we have ordered and defined our "physical environs" and "social milieu," so that we no longer see ourselves as part of nature. Yet, humans are part of and have a major influence on many, if not most ecosystems (Haury, 2002). In order to maintain and improve environmental quality, we must understand the complexities of our interrelationships with the environment (Heimlich, 1992). Through the use of a pedagogy based on systems thinking, students can develop the "habits" that allow them to see these interrelationships.

A Need for Systems Thinking in Fourth Grade Environmental Education

As discussed, systems thinking has been part of the conversation in sustainability education for some time. In addition, formal, intentional uses of systems thinking concepts are finding their way into some standards-based K-12 education systems. However, readily available environmental education materials for elementary education, specifically fourth grade, are lacking. This thesis provides three learning modules that help begin to fill in this gap.

The Waters Foundation's mission is to increase the number of educators that apply systems thinking concepts, habits, and tools in the classroom. This is pursued through three strategies: development (informing, training, sustaining), dissemination (website, publications, conferences), and research (action research) (Waters Foundation, 2010h). The website provides a list of downloadable classroom lessons in the subjects of: art, foreign language, health, language arts, math, science, social studies, and an introduction to systems thinking. Of the science lessons, two focus on environmental issues: "Global Warming CLDs," and "S-shaped Growth and Sustainability." The "Global Warming CLDs" is appropriate for grades 6-9, while the "S-shaped Growth and Sustainability" is appropriate for grades 6-12. Of the 27 science lessons, only six of the lessons are suitable for the forth-grade level. The majority of the lessons (14) are for grades 5-12.

The Creative Learning Exchange provides games and activities to "encourage an active, learner-centered process of discovery in K-12 education…through the mastery of systems thinking and system dynamics modeling." The Shape of Change (Quaden & Ticotsky, 2008) and The Shape of Change: Stocks and Flows (Quaden & Ticotsky, 2009) are two of their publications, which, respectively, contain games and classroom activities to examine changes over time and why the changes occurred. The lesson plans are cross-curricular, but mostly science-based with a few environmental topics (e.g. tree planting and harvesting, and keystone species). In The Shape of Change, the grade level is not specified for the lesson plans; however, they do require "high level critical thinking" and contain "sophisticated content," and are therefore more appropriate for levels well above fourth grade.

Linda Booth Sweeny has published The Systems Thinking Playbook (Sweeny & Meadows, 1995) and When a Butterfly Sneezes: A Guide for Helping Kids Explore Interconnections in Our World Through Favorite Stories (Sweeney, 2001). The Systems Thinking Playbook emphasizes the concepts and habits of a systems thinker through games. The games in The Systems Thinking Playbook are structured to teach the concepts and the habits of mind of systems thinking without a focus on any particular context. However, they can be applied to real scenarios, including environmental issues. The games are not geared to one specific grade level; however, many of the games are too advanced for fourth grade. When a Butterfly Sneezes is a collection of children's stories that contain key systems thinking principles. Linda Booth Sweeney uses folktales and children's stories to help children understand systems because they contain insights about how living systems work; furthermore, they are practical for introducing systems to children. The stories cover a broad range of themes, including science, and can be used with children of all ages.

CHAPTER 2 – THE CASE STUDY: BACKGROUND, HABITS OF A SYSTEMS THINKER APPLIED IN THE CASE STUDY, & OUTLINE OF THE LEARNING MODULES

A Local Context – The Case Study on Climate Change

Why Climate Change?

Climate change is a quintessential example of behavior that emerges from a complex system. Climate change has a global spatial scale, a time scale much beyond normal experience of individual humans, long time-delays, and complex dynamics (Sweeney & Sterman, 2002). Research by Sweeney & Sterman (2002) suggests that although the majority of Americans believe that global warming should be addressed, highly educated people have an extremely poor understanding of global warming. The subjects in their study underestimated time delays, and did not recognize important feedbacks and stock and flow structures. Sweeney & Sterman (2002) hypothesize that poor systems thinking skills (i.e. habits of a systems thinker – "habits") are the root to complacency about climate change – failing to identify and understand feedback, time delays, and stock and flows leads to incorrect inferences on how the climate responds to human activities. This in turn leads to overly optimistic views of how quickly the problem of global climate change can be addressed and can feed a "wait and see" posture toward the problem.

Sweeney & Sterman's (2002) research subjects were highly educated adults and the study evaluated climate change understandings that are well above what should be expected from elementary school students. However, the activities developed and described in this thesis provide a beginning point for further systems thinking lessons on climate change.

The climate change case study developed here illustrates the following systems thinking concepts: how important characteristics change over time, the importance of feedback, stocks and flows, and interdependencies. These concepts and accompanying systems thinking tools (Table 3) are fully described and illustrated later in this chapter. Through the use of systems thinking tools and activities, students will able to more fully grasp important features of the climate change problem and recognize their place in the system; these modules can also reinforce some of the "habits," which Sweeney & Sterman's research indicated were lacking, and which are outlined in Table 2. Moreover, by focusing on their local context (Lake Michigan), students may better understand this global situation. Lake Michigan is the significant local body of water for these students, and is thus well-known. Hence, the modules described in this thesis use Lake Michigan and the surrounding ecosystem as the context for helping students understand the potential impacts of global climate change.

Background: Lake Michigan and Climate Change

Hudson (2001) suggests that environmental education in the 21st century must be in the interest of the community. The students involved in the program are from the metro Chicago area. Growing up in an urban environment, Lake Michigan is one of the closest and well-known natural spaces for them. They have grown up going to the beaches of Lake Michigan, boating and swimming in its waters, and drinking its water. In discussing such a complex issue of climate change in a context that is familiar to them, it is hoped that this will help the students better understand and appreciate what they are learning.

In May 2008, the Healing Our Waters® - Great Lakes Coalition published a report titled "Great Lakes Restoration & the Threat of Global Warming" (Dempsey, Elder, & Scavia, 2008). The report summarizes the potential impacts that climate change might have on the Great Lakes. Contributions to this report were made by the Union of Concerned Scientists and the Ecological Society of America. Further resources were provided by the National Park Service, the Presidential Climate Action Project, the Brookings Institute, and many others. The report is a synthesis of the *likely* impacts warming temperatures will have on the Great Lakes; we cannot know the full extent of the impacts, we can only make predictions based on the best scientific knowledge available. Below are summarized some of the likely major ecological impacts described in that report.

Assuming global carbon emissions continue to grow at their current rates, the Great Lakes region is projected to have a temperature increase of 5.4 – 10.8°F relative to temperatures from 1961-1990. As a result, the growing season may start 15-35 days earlier and the first frost may arrive 35 days later. This temperature increase would cause lakes to warm, increasing evaporation, decreasing ice cover, and lowering water levels – Lake Michigan water levels could drop by three feet, one foot within the next century. Fish egg mortality would also result from a decrease in ice cover, lowering the strength of juvenile fish. As the length and timing of the seasons change, as noted above, the turnover rate would be affected. Turnover is the complete mixing of the lake water mass during the fall and winter as a result of temperature gradients in the water column. During this process, oxygen-rich surface water is brought to the depths, while nutrient-rich bottom water is brought to the surface. Changes in the timing of turnover events may reduce nutrient supplies to surface waters and lead to anoxic, or oxygen-devoid, bottom conditions. Toxic chemicals (PCBs and mercury) trapped in sediments would be released from the increased water temperatures and decreased water levels.

The region may also experience more intense storm events, eroding soil and increasing the runoff that transports the soil. Agricultural pollutants (nitrates, phosphorous, and pesticides) attached to sediment would be transported to waterways; sewage systems would reach their maximum and overflow. Beach closings and costs to maintain water quality goals, including our drinking water supply, would increase. Increased algal growth that sustains high concentrations of pathogenic bacteria would increase, posing harm to fish, birds, and humans. With all these changes, native species may lose habitat; invasive species find may find these habitats more suitable, out-competing native species. Some species may be able to re-locate and find more suitable habitat elsewhere, while others would not be able to survive.

While the fine details of these impacts are too complex for fourth graders to grasp, the broader implications associated with these changes can be explored. The learning modules were designed to accomplish an understanding of the broader implications.

Habits of a Systems Thinker, along with Supporting Concepts and Tools, Applied in the Case Study

As stated in Chapter 1, a systems thinker is one who has internalized the habits of a systems thinker (Waters Foundation, 2010k). The particular "habits" that we seek to develop through the learning modules described herein are outlined below and in Table 2. As represented in Figure 1, these "habits" implicitly use certain systems thinking concepts, and are explored and practiced through the use of systems thinking tools (Figure 1). Such tools enable the communication of one's understanding of a system's structure and behavior through graphic illustrations, and enable one to visualize dynamic complexity (Pegasus Communications, Inc, 2000-2004; Waters Foundation, 2010l).

Table 3 reproduces the habits of a systems thinker mentioned earlier (from Table 1) and shows the connections between these "habits," the systems thinking concepts, and the tools used in the case study learning modules. The rest of this section more fully describes the systems thinking concepts and the tools in Table 3.

Experiential exercises, or games, are also primary tools in this case study along with the specific systems thinking tools. Experiential exercises can engage those with different learning styles, provide a safe environment to test theories and evaluate options, and represent the structure and behavior of reoccurring patterns of behavior (Sweeney & Meadows, 1995). Furthermore, Barab & Dede (2007) posit that the understanding of scientific facts, concepts, or principles is facilitated through game-like learning experiences. Not only are experiential exercises fun; they involve interaction with others and the ability to make mistakes without much consequence (Sweeney & Meadows, 1995). Games can do also do the following: motivate, release energy, improve team building skills, create metaphors and a shared vocabulary, explain the relation between structure and behavior, assess the level of understanding, test alternative decisions, and provide future scenarios (Meadows, 2008). Depending on the nature of the exercises or games, they can reinforce any of the habits of a systems thinker.

Table 3. A list of the habits of a systems thinker (Table 2), corresponding systems thinking concepts, and the systems thinking tools utilized in this case study.

Habits of a Systems Thinker	Systems Thinking Concept	Systems Thinking Tool
Identifies the circular nature of complex cause and effect relationships	Balancing and reinforcing feedback	Causal loop diagram (CLD)
Describes how things accumulate or diminish over time (stock and flow dynamics)	Stocks and flows	Bathtub model
Observes how elements within systems change over time, generating patterns and trends	Change over time	Behavior over time graph (BOTG)
Looks for connections among elements in a system	Interdependencies	Causal loop diagram (CLD)
Sees self as part of the system	Interdependencies	Causal loop diagram (CLD)

HABIT: Identifies the circular nature of complex cause and effect relationships

In dynamic systems, cause and effect relationships are circular (Waters Foundation, 2010f). This circular nature connotes feedback processes. Feedback occurs "…when the effect of a cause re-effects the next iteration of the cause" (Waters Foundation, 2010e). A systems thinker who develops this habit will search for these circular connections, seeing a more complete picture of the system than if only identifying linear relationships.

Supporting Systems Thinking Concept: Feedback – Balancing and Reinforcing

Sterman (2000) designates feedback and stocks and flows as the two central concepts of dynamic systems theory. The dynamics of a system are determined by: feedback processes, stock and flow structures, time delays, and non-linearities (Sterman, 2000). Feedbacks among the components in a system are the cause of most complex behaviors (Sterman, 2000). Instead of simple linear cause and effect, feedback is a circular causality (Waters Foundation, 2010i). Two types of feedback drive the dynamics of a system: reinforcing or positive feedback and balancing or negative feedback (Sterman, 2000; Waters Foundation, 2010d). Reinforcing feedback reinforces or amplifies a condition, whereas balancing feedback counteracts or opposes change (Sterman, 2000). Balancing conditions are self-limiting and seek equilibrium; in reinforcing conditions, a small change builds on itself to become a large change (Waters Foundation, 2010e). Feedback is illustrated through a CLD (Figures 2 & 3), a connection circle, or experiential exercises.

Feedback is an important concept in this case study because it helps describe why CO_2 is accumulating in the atmosphere (Learning Module #1) and how Lake Michigan is being affected by climate change (Learning Module #3). In Learning Module #1, the students learn that plants and animals comprise a balancing feedback loop, maintaining a balance of CO_2 in the atmosphere. When anthropogenic CO_2-producing activities become part of the system, the balance is upset. The balancing feedback concept is taught through an experiential, hands-on exercise. In Learning Module #3, a simplified component of a healthy Lake Michigan ecosystem is represented by a positively reinforcing feedback loop. Changes in the Lake Michigan ecosystem caused by climate change interfere with this feedback, causing the feedback to become negatively reinforcing. This reinforcing feedback concept is taught through CLDs and an experiential, hands-on exercise.

Systems Thinking Tool Utilized to Apply Concept: Causal Loop Diagram (CLD)

A CLD (Figures 2 & 3) is a diagram consisting of four elements that aids in understanding and communicating the interactions that drive a dynamic system. CLDs are utilized in this case study because they “illustrate how structure generates behavior within a system” (Waters Foundation, 2010d). Along with BOTGs, CLDs are one of the tools determined by Costello, et al. (2001) as a focus for elementary grades.

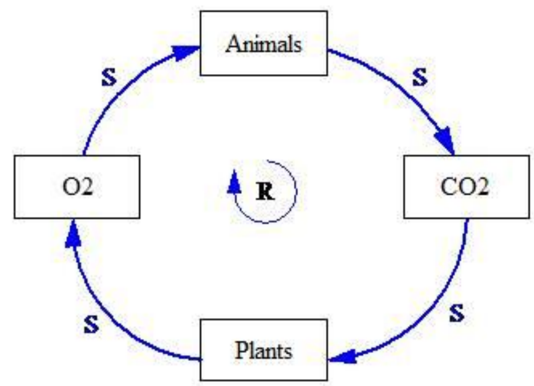


Figure 2. A CLD that represents a simplified relationship among plants and animals that could be understood by fourth graders. This system is characterized by a reinforcing feedback loop.

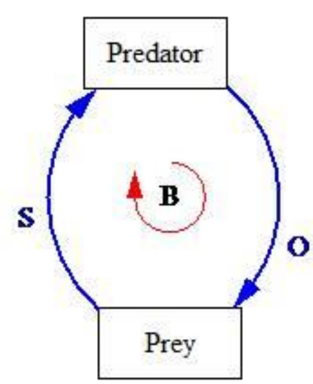


Figure 3. A CLD that represents a simplified relationship between predators and prey that could be understood by fourth graders. This system is characterized by a balancing feedback loop.

The four elements of a CLD are: variables, causal links, the polarities of the causal links, and feedback loop identifiers (Waters Foundation, 2010d). Rules to naming the variables can be found on the Waters Foundation website and in Sterman (2000). Variables are connected by arrows, denoting which variables affect other variables. The 'S' and 'O' symbols associated with the arrowhead describe how one variable is influenced by another. An ‘S’ signifies that the variables move in the same direction (i.e. if a variable increases, the affected variable will be greater than it would have been without the influence). An ‘O’ signifies that the variables change in opposite direction (i.e. if a variable increases, the affected variable will be less than it would have been without the influence). The central symbol identifies the loop as reinforcing or balancing. A reinforcing loop (R) will either grow or shrink, whereas a balancing loop (B) will move toward, return to, or oscillate around a specific condition. If there is a large time delay between the cause and effect of two variables, a time delay symbol (two parallel lines) is placed on the arrow connecting the two variables. When creating a CLD, it is important to keep the audience and purpose in focus (Sterman, 2000). This will determine how simple or complex the CLD will be. Multiple CLDs can be connected together, if required by the nature of the system.

HABIT: Describes how things accumulate or diminish over time (stock and flow dynamics)

The state of a system is characterized by the stocks (something that accumulates) in the system (Sterman, 2000). Stocks are also the sources of time delays and inertia in a system (Sweeney, n.d.b). A systems thinker who develops this habit would thus be better able to understand why a system behaves like it does.

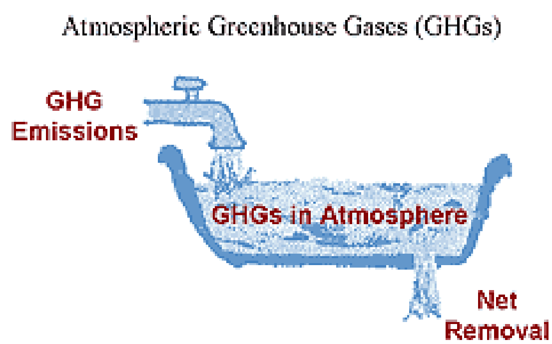
Supporting Systems Thinking Concept: Stocks and Flows

A stock is an accumulation, or anything that builds up or dwindles (Sterman, 2000; Waters Foundation, 2010d). A flow is the rate at which conditions, or the state of the system, change (Sterman, 2000; Waters Foundation, 2010e). A stock, a unit of material, is changed by the inflows and the outflows, units of material per time period (Sterman, 2000).

The learning module Learning Module #1 includes the concept of stocks and flows. The stock is CO_2 in the atmosphere. The flows are the rates of CO_2 entering the atmosphere (via animals, factories, and cars) and being removed from the atmosphere (via plants). This concept was expressed through a large bathtub model with moveable pieces to create different stock and flow relationships.

Systems Thinking Tool Utilized to Apply Concept: The Bathtub Model

A good analogy for a stock and flow system is a bathtub (Figure 4) – the water in the bathtub is the stock, whereas the rates of water flowing in through the faucet and exiting through the drain are the flows. Stocks and flows can be demonstrated through this bathtub analogy, experiential exercises, or stock/flow maps.



Source: John Sterman, MIT Sloan School of Management

Figure 4. Bathtub model of atmospheric greenhouse gases (GHGs). 'GHGs in atmosphere' (water in the tub) is the stock; 'GHG emissions' (rate of water flowing through the faucet) and 'net removal' (rate of water flowing through the drain) are the flows.

HABIT: Observes how elements within systems change over time, generating patterns and trends

The values of the elements in a system change over time (Waters Foundation, 2010f). A systems thinker who develops this habit will have a better understanding of the interdependence of the elements in the system and that system's structure (Waters Foundation, 2010f).

Supporting Systems Thinking Concept: Change over Time

In discussing feedback and stocks and flows, the concept of change over time has already been introduced – the amount of stock within a system *changes over time* (Waters Foundation, 2010e). These changes are usually induced from interconnectedness in a system (Waters Foundation, 2010i) – the connections among the components in a feedback system create the dynamics, or continuous *change*, of the system (Sterman, 2000). Change of time can be illustrated through BOTGs (Figure 3).

Both Learning Module #1 and Learning Module #2 focus on the concept of change over time. In Learning Module #1, the students learn how CO_2 in the atmosphere has been affected over time by human activities. In Learning Module #2, the students learn how the increase of CO_2 in the atmosphere is correlated with an average global temperature increase. This concept is applied through an experiential exercise and BOTGs.

Systems Thinking Tool Utilized to Apply Concept: Behavior over Time Graphs (BOTGs)

A BOTG (Figure 5) is a basic line graph depicting a variable's pattern of change over time.

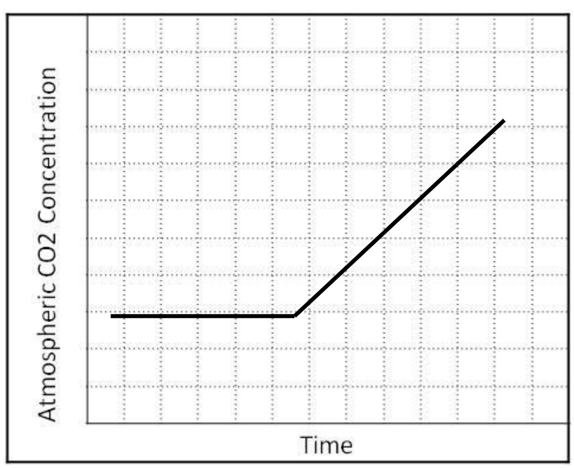


Figure 5. A simplified example of a BOTG depicting atmospheric CO_2 concentration over time

Instead of focusing on an isolated event, a BOTG focuses on change over time, generating discussions about how and why that variable is changing (Waters Foundation, 2010b). BOTGs are one of the tools determined by Costello, et al. (2001) as a focus for primary grades, along with CLDs, simple system dynamic models, and some stock/flow diagrams. Graphs are also introduced in prior grades; therefore, the students would not have to learn a new educational tool along with a new and complex subject.

The x-axis of a BOTG has the units of time (e.g. years, months), while the y-axis represents the variable, either concrete or abstract, in consideration; the scale for the y-axis variable must be defined. When interpreting a BOTG, it is important to note why the time scale starts and ends where defined, and why and when the variable changes behavior (Waters Foundation, 2010c). One can also plot multiple variables on the same BOTG to determine if there is any correlation among the variables (Waters Foundation, 2010c).

HABIT: Looks for connections among elements in a system (including HABIT: Sees self as part of the system)

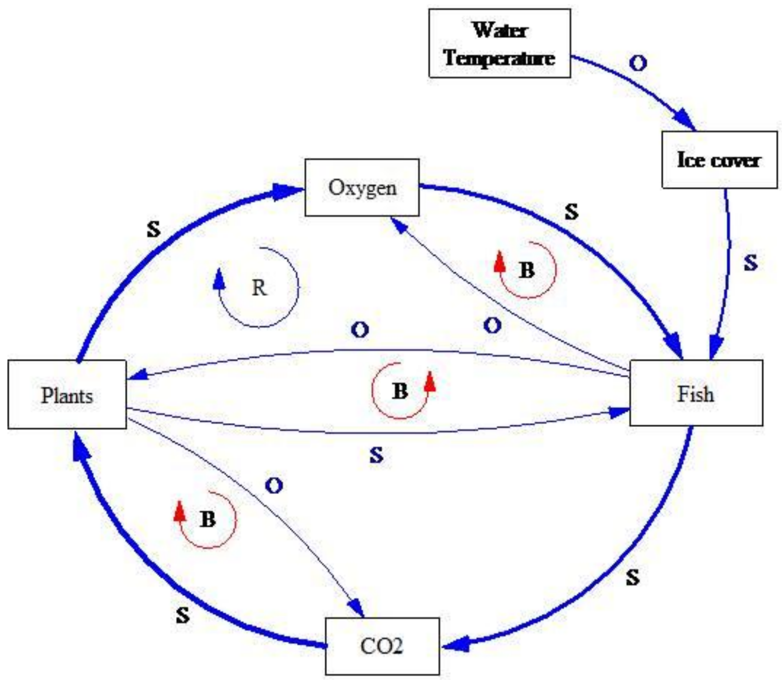
A systems thinker who develops this habit will assume that no element is isolated from another (Sweeney, n.d.b.). When this is done, connections become apparent among things and situations that may have been overlooked before become important. Connections can be seen among ourselves, nature, and events that influence our lives (Sweeney, n.d.b.), which corresponds to the habit: *sees self as part of the system*.

<u>Supporting Systems Thinking Concept: Interdependencies</u>

The concept of interdependencies has also already been introduced. Interdependencies occur when the components of a system affect each other, as seen with feedbacks (Waters Foundation, 2010c). It is not the components of the system that create a dynamic system, but the interdependencies of the components (Sterman, 2000; Waters Foundation, 2010e). Thus, interdependencies are also present in the learning modules that contain feedbacks and are expressed through their corresponding tools (Learning Module #1 & Learning Module #3)

<u>Systems Thinking Tool Utilized to Apply Concept: Causal Loop Diagrams (CLDs)</u>

Shown below in Figure 6 is a CLD that illustrates both feedback (balancing and reinforcing) and other causal links indicating the interdependencies in this simplified ecosystem.



<u>Figure 6.</u> A CLD of a simplified healthy lake ecosystem being affected by climate change. The circle is the healthy lake ecosystem – a reinforcing feedback loop among the oxygen, fish CO_2, and plants. An increase in water temperature due to climate change causes ice cover to decrease, which in turn harms the fish – the loop then becomes a vicious cycle – the fish have trouble surviving, therefore the plants have trouble surviving, and this continues.

HABIT: Sees the whole, or the big picture

Instead of just looking at one event, or one element of a system, a systems thinker takes a “step back” from the situation and thinks about the connections among the elements (Sweeney, n.d.b; Waters Foundation, 2010f). The details of the elements do help to understand the system as a whole, but in the end, the ability to see the big picture is what really constitutes a *systems* thinker.

All the concepts and tools in this case study are aimed at helping the students first achieve a big picture understanding of each of the separate climate change concepts in the three learning modules, and ultimately, climate change as a whole.

Outline of the Learning Modules in the Case Study

Chapter 3 describes in detail the methods developed for the Lake Michigan case study. The actual learning modules, which are prepared for use by educators, are found in Appendix 3. Below is a brief description of these learning modules, represented in Figure 5. For each module, we highlight the module theme, the science content, the relevant habits of a systems thinker, the systems thinking concepts, the systems thinking tools, the experiential component (if relevant), the learning objectives, and the assessment methods.

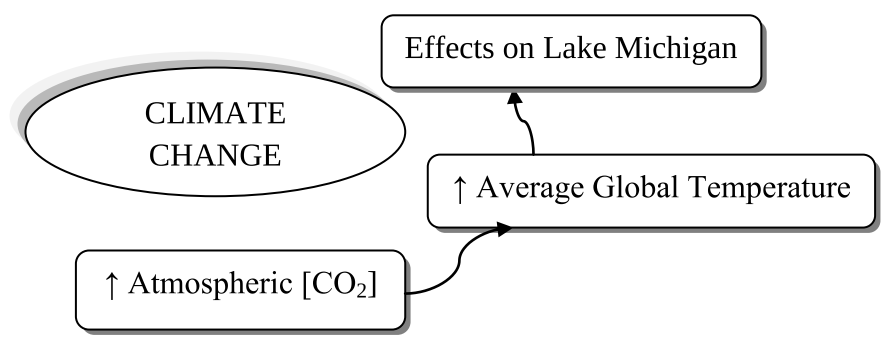


Figure 5. An illustration of the three learning modules created for the case study

Learning Module #1

Theme: Atmospheric CO_2 and climate change

Science Content: This module addresses the increase of CO_2 in the earth's atmosphere due to anthropogenic activities. Exploring this requires a *big picture* understanding of the dynamics in which the earth seeks to *balance* the uptake and outflow of CO_2 (*stock and flow*) from the atmosphere, and how these dynamics have *changed over time* because of anthropogenic activities.

Relevant Habits of a Systems Thinker:

Habit: Observe how elements within systems change over time

CO_2 concentrations in the atmosphere are influenced by natural and anthropogenic activities. This understanding is reinforced through a role-playing game in which students experience and track how an imaginary atmosphere's CO_2 concentrations might change over time. Students acting as CO_2 emitters and consumers will respectively add and subtract CO_2 from the atmosphere.

Habit: Sees self as part of the system

By participating in the role-playing activity in which anthropogenic activities are introduced as CO_2 producers, students will be able to see how humans influence the dynamics of CO_2 in the atmosphere.

Habit: Describe how things accumulate or diminish over time (stock and flow dynamics)

One integral concept in global climate change is the idea that the atmosphere serves as a "reservoir" in which CO_2 accumulates, diminishes, or remains constant over time. Through the use of a "bathtub metaphor," which is widely used in system dynamics circles, students will further learn how the CO_2 emitters and consumers from the role-playing game act as "CO_2 inflows" and "CO_2 outflows," respectively, to the atmosphere. Changes in the rates of flow will affect the atmospheric CO_2 levels over time. BOTGs will be drawn to reflect the changes in CO_2 concentration over time affected by different rates of flow. In this way, students will be able to describe how natural and anthropogenic activities affect atmospheric CO_2 levels.

Systems Thinking Concepts: Change over time, balancing feedback, stocks and flows

Systems Thinking Tools: Bathtub metaphor, behavior over time graphs (BOTGs)

Experiential component: To first introduce how CO_2 concentrations in the atmosphere are influenced by natural and anthropogenic activities, each student is given a role: plant, animal, car, or factory. Objects representing CO_2 are placed inside a marked circle on the ground, which represents the atmosphere, and this number is recorded. First, plants and animals, respectively, take objects out of the atmosphere and place objects into the atmosphere. The number of objects in the circle is recorded. Cars and factories then join the plants and animals, placing objects into the atmosphere. The number in the circle is recorded. These same roles are discussed in the bathtub metaphor, in reference to this activity.

Learning Objectives:

- Students will identify some human activities that affect atmospheric CO_2 and explain how the activities affect it.
- Students will use the bathtub analogy to predict what will happen to CO_2 if emissions are continued at the same level, if emissions are reduced but not below the rates at which CO_2 is removed from the atmosphere, or if emissions are reduced below the levels at which CO_2 is removed from the atmosphere.
- Students will match BOTGs of CO_2 trends with the appropriate bathtub analogy scenario.

Assessment: Match three statements on the level of CO_2 in the atmosphere with three BOTGs.

Learning Module #2

Theme: Increase in average global temperature

Science Content: This module addresses the increase in average global temperature, which correlates with the increase of CO_2 and other greenhouses gases in the atmosphere. Exploring this requires an understanding of both average global temperature and atmospheric concentrations of CO_2 *changing over time*.

Relevant Habits of a Systems Thinker:

Habit: Observes how elements within systems change over time, generating patterns and trends

Global warming is an average increase in the earth's temperature, which causes changes in climate. Students plot five specific points over a 160 year period on a template of a "Temperature" BOTG, visually illustrating this change over time.

Habit: Looks for connections among elements in a system

The average global temperature increase that the earth is experiencing is correlated with an increase in the atmospheric concentration of CO_2 and other greenhouse gases. A BOTG displaying both increases is shown to the students. This visual tool helps the students make a connection between these two elements of climate change.

Systems Thinking Concepts: Change over time

Systems Thinking Tools: Behavior over time graphs (BOTGs)

Learning Objectives:

- Students will create a BOTG of global temperature change over time and describe the graph in words.
- Students will analyze a BOTG of global temperature change and CO_2 trends and explain what is happening to temperature and why.

- Students will analyze a BOTG of global temperature change and CO_2 trends and predict that global temperature will continue to increase with a continued increase in CO_2.
- Students will suggest effects that this increase in temperature may have on the environment.

Assessment: Write answers to questions concerning: temperature change over time, the correlation between temperature change and atmospheric CO_2 concentration, future temperature trends, and possible effects on the environment.

Learning Module #3

Theme: Effects of climate change on Lake Michigan

Science Content: This module addresses the possible effects of climate change on Lake Michigan. Exploring this requires a *big picture* understanding of the *interdependencies* among the elements in a simplified healthy Lake Michigan ecosystem. Effects from climate change alter the *feedbacks* in a healthy ecosystem, changing the dynamics of the system.

Relevant Habits of a Systems Thinker:

Habit: Looks for connections among elements in a system

An ecosystem is comprised of numerous elements that "work" together to create a functioning and thriving ecosystem. The connections among a healthy Lake Michigan ecosystem are made through a drawing of a CLD and a creation of a 'human web' in which the students represent the elements in an ecosystem connected together by a ball of yarn.

Habit: Identifies the circular nature of complex cause and effect relationships

Some connections in an ecosystem create cause and effect relationships that help reinforce the ability for the ecosystem to function. The CLD and "human web" created by the students illustrate this circular nature of the connections among the elements. Adding possible effects to Lake Michigan caused by climate change to the CLD and to the "human web" demonstrates how an "outside" input to the system influences the behavior of the system.

Habit: Sees the whole, or the big picture

By this point, the students have learned about climate change, from its causes all the way to its effects, creating a simplified *big picture* of climate change.

Systems Thinking Concepts: Interdependencies and feedbacks

Systems Thinking Tools: Causal loop diagrams (CLDs)

Experiential Component: In order to visualize the interdependencies among the elements in a simplified healthy Lake Michigan ecosystem and how this ecosystem may be affected by climate change, students are each given a role: oxygen, CO_2, fish, or plants. A ball of yarn is passed among these students to make the proper connections in the ecosystem, creating a "human web" – this web is considered a simplified "healthy" Lake Michigan ecosystem. Due to climate change, an increase in water temperature reduces ice cover, and an increase in intense storms leads to more water pollution. Both of these scenarios are separately introduced to the "healthy" ecosystem, with students connecting to the "human web" as the new elements.

Learning Objectives:

- Students will use a CLD to identify the relationships among organisms and their resources in their environment.
- Students will use a CLD to predict and describe the effects of climate change on Lake Michigan that are due to habitat changes and loss of resources.

Assessment: Verbally answer questions as a group concerning specific affects from climate change on Lake Michigan.

CHAPTER 3 – CASE STUDY: CURRICULUM DESIGN & PILOT STUDY METHODS

Curriculum Design

Science Education

According to the Board on Science Education, Center for Education, Divison of Behavioral and Social Sciences and Education [Board on Science Education] (2006), "To be successful in science, students need carefully structured experiences, instructional support from teachers, and opportunites for sustained engagement with the same set of ideas…" For this to be achieved, "standards and curriculum should lay out specific, coherent goals for important scientific ideas and practices…" (Board on Science Education, 2006). Science standards should help define curriculum content, and thus guide curriculum design to be appropriate developmentally and to be scientifically rigorous (Bybee, 2006). Science teaching stragies must consider a diversity of student learning strategies (Bybee, 2006). Furthermore, the ability for children to think both concretely and abstractly should be taken into consideration when designing teaching strategies (Board on Science Education, 2006). The development of the learning modules for the case study used a standards-based approach, discussed below, in order to comply with the above statements. Following the science standards for the selected fourth grade level allowed for developmentally appropriate, yet challenging learning content. Teaching strategies were developed from the standards, keeping in mind the students' thinking capabilities and different learning strategies.

Backward Design

The learning modules for this thesis were developed using the principles of "backward design." Backward design is a standards-based curriculum design, which focuses more on the *learning* by the students than the *teaching* by the teachers (Wiggins & McTighe, 2005). The idea behind backward design is that standards present the framework for identifying learning priorities, and thus guide curriculum design (Wiggins & McTighe, 2005). In backward design, curriculum development begins with the determination of the desired results, and lessons are planned to reach these goals (Wiggins & McTighe, 2005). This contrasts with activity-oriented design, common at elementary level curriculum design, which can lack specific focus on learning priorities (Wiggins & McTighe, 2005).

Wiggins & McTighe (2005) have designated three stages of backward design. Backward design is a component of Wiggins & McTighe's "Understanding by Design" framework. Other versions of these three stages have been created by other educators to meet their visions. Wiggins & McTighe's (2005) three stages are as follows:

- Stage 1: Identify desired results
- Stage 2: Determine acceptable evidence
- Stage 3: Plan learning experiences and instruction

In Stage 1, the content standards are examined and the learning goals are determined (Wiggins & McTighe, 2005). In Stage 2, the assessment is determined to establish that the desired goals have been achieved (Wiggins & McTighe, 2005). In Stage 3, the activities are determined to best equip the students with the knowledge and skills needed to achieve the desired goals (Wiggins & McTighe, 2005).

Wilson (2002, 2005) suggests an additional first stage, "Step 1," to Wiggins & McTighe's (2005) sequence: "What is your vision of your learners at the end of their contact with you?" The addition of "Step 1" is important because it directs attention to the characteristics of the learners (demographics, skills, level of understanding) and what the teacher hopes the learners will "look like" after the lessons (Wilson, 2002, 2005). This was an important step in the creation of the learning modules for this thesis. Wilson (2002, 2005) also suggests a firth stage, "Step 5," which includes reflection, evaluation, and revision.

Backward Design and the Creation of the Learning Modules

For the development of the learning modules, an approach more similar to Wilson's (2002, 2005) five-step backward design was followed. The one significant difference between the development of the learning modules and the curriculum design strategy of backward design is that the method of learning, systems thinking, was pre-determined. However, the actual tools, materials, and activities were determined based on the learning objectives that were developed from the ILSS, which follows the principles of backward design.

Step 1: Vision of the learners upon completion of the learning modules

The first step in the creation of the three learning modules coincided with Wilson's (2002, 2005) "Step 1." The age, skills, and levels of understanding for the target grade-level were taken into consideration early in the module development process. Based on what was known about the students, the systems thinking habits, concepts, and tools needed to gain a deeper understanding were identified. Giving consideration to what these students would gain from the learning modules, awareness and greater understanding of what affects the environment around them was an important part of the process.

Step 2: Determine what to teach and the desired results

Considering the fourth grade as the target grade-level, the Performance Descriptors in the Illinois Learning Standards for Science (ILSS) under Stages C, D, and E were examined to determine which environmental issue would be appropriate for this grade. The Performance Descriptors for fourth grade involve both the causes of climate change and the effects of climate change on biotic communities. Climate change was chosen because it is a pertinent issue, it can be applied both globally and locally, and there are many systems present in both the causes and the effects. Lake Michigan was determined as the case study since it is a local environment enjoyed and studied by many students in Illinois. The Performance Descriptors chosen are listed in Appendix 2[1]. From

[1] Both a description on the ILSS and the Performance Descriptors for the learning modules are in Appendix 2.

these Performance Descriptors, specific learning objectives were chosen, keeping in mind the systems thinking pedagogy.

Step 3: Determine evidence and plan evaluation

Assessment sheets were developed to accompany the learning modules. Each question in the assessment was made to reflect the learning objectives. Assessments were also created to reflect different learning styles; therefore they include writing, matching, and speaking.

Step 4: Plan learning experiences and delivery methods

The Systems Thinking Playbook by Linda Booth Sweeney and Dennis Meadows (1995) was examined to gain insight as to how systems thinking habits, concepts, and tools are applied in an educational setting. Some of the activities developed for these learning modules were inspired by activities in this book. Although the systems thinking methodology was pre-determined, "habits," concepts, and tools were not. Factors in Step 1 guided the selection of the habits of a systems thinker, and thus systems thinking concepts and tools, that would be appropriate to introduce at this grade-level in order to achieve the desired learning results.

Step 5: Reflect, evaluate, and revise

I met twice with St. Luke School's Resource Specialist, who works with children in all grades at the school (K-8). Her main objective was to confirm that the learning modules were grade-appropriate. As a faculty member at St. Luke School for 20 years, she gave advice on how to successfully implement a pilot program. The learning modules were refined multiple times, with guidance from the Resource Specialist, to best meet the overall vision of the curriculum. The whole development process was ongoing; thus at times, Step 4 may have preceded Step 3.

The Pilot Study of the Learning Modules

Logistics

On July 27, 2010, eight students, four girls and four boys, from St. Luke School in River Forest, Illinois were present for the implementation of the learning modules. The students had completed fourth grade in early June, and would be entering fifth grade in late August. The home of one of the students was used as the location. The three learning modules were completed within a two-hour time-frame, from 10am until 12pm. Each student had his or her own folder with all of the necessary materials inside. Due to excessive heat that day, all of the teaching was done inside, except for the first part of the first learning module (Climate Change: Increase in CO_2 in the Atmosphere).

The Students

The students at St. Luke begin receiving a science education in kindergarten, when science is integrated into the curriculum through reading. From first to second grade, science is taught two to three times per week, alternating with social studies. From fourth to eighth grade, science becomes a part of the every-day curriculum. A recycling program has been active in the school for at least 15 years. A Green Club was recently started at the school, which has helped build more awareness on environmental issues.

These particular students come from middle to upper-middle class families with parents who have college or master's degrees, and white-collar, professional jobs. Two students have teachers for parents. All students, except for one, come from households with both parents. Education is a priority for these families; there are plenty of educational opportunities for their children at home outside of the classroom, including family travel. These students are raised in homes where the expectations are high, and therefore, the students have high expectations for themselves. Watching educational programming on TV, such as Animal Planet and The Discovery Channel, is common, as well as limited access to video games.

The eight students represented a cross-section in terms of place in the family – oldest, middle, and youngest. They have been students at St. Luke since kindergarten or first grade.

CHAPTER 4 – RESULTS AND DISCUSSION

As stated in Chapter 1, this thesis aims to answer the following two questions:

1. What evidence can an informal pilot learning experience provide that a systems thinking pedagogy will achieve selected learning objectives within the Illinois Learning Standards for Science (ILSS)?
2. Does the use of a systems thinking pedagogy provide insights and understanding in fourth grade students that would not be achieved otherwise?

This chapter summarizes the findings from the pilot study described in Chapter 3 and seeks to address how those findings give insight to each of the above questions. We begin with the detailed results from observations for each of the learning modules, then proceed to document the overview of our findings with respect to the above questions. Following these results is a discussion on the subsequent topics:

- External factors that affected the outcomes
- Limitations of the findings from this study
- Did systems thinking deliver what I expected?
- Suggestions for further research
- Lessons learned: Ways to improve the case study

Results

Observations from Each of the Learning Modules

Learning Module #1 – Climate Change: Increase in CO_2 in the Atmosphere

While participating in the role-playing activity, each student was able to properly play his or her role – cars, factories, and animals put CO_2 into the atmosphere, while plants removed CO_2 from the atmosphere. They immediately noticed while playing the game that the amount of CO_2 in the atmosphere was increasing when cars and factories entered the scenario. During the bathtub demonstration, the students were very verbal and interactive. They were able to correctly determine how the bathtub would be affected by the different scenarios. The students were able to properly describe how each of the graphs for each of the bathtub scenarios should be drawn and to match graphs to specific scenarios on CO_2 trends.

Learning Module #2 – Climate Change: Increase in Average Global Temperature

While graphing the global temperature change over time, the students immediately noticed how the graph, and therefore the temperature, was increasing. Their enthusiasm was palpable, and they appeared to be very comfortable with the relationship between temperature and CO_2 concentration. This activity was slightly more challenging than anticipated; however, the students assisted each other to find success in the exercise. Ultimately, each student was able to draw a proper graph. Students were also able to properly make predictions and extend the graph into the future based on the evidence they were provided.

Learning Module #3 – Climate Change: Effects on Lake Michigan

This activity had more mixed responses from the students than the other activities. Instead of instant observations and comments from the students, I had to prompt them for their observations. The more knowledgeable students of the group on this topic were able to better grasp the concepts and focus on their tasks. By this point, they were more concerned with playing with the yarn and making it more tangled, than properly participating. However, as the web became more complex, the students tried to look for ways that elements of the web could be more interconnected. By the third web, the participating students were able to make the proper connections among the elements on their own. Some of the students were able to describe what would happen to the web if it was affected by changes in the environment due to climate change.

Results on the Questions

Question 1: What evidence can an informal pilot learning experience provide that a systems thinking pedagogy will achieve selected learning objectives within the Illinois Learning Standards for Science (ILSS)?

Learning Module #1 – Climate Change: Increase in CO_2 in the Atmosphere

Based on the success of both the role-playing game and the bathtub demonstration, this activity would satisfy the ILSS. The students were able to demonstrate their understanding of human activities (e.g. driving cars, flying planes, making electricity, and using factories) affecting the concentration of CO_2 and other greenhouse gases in the atmosphere, which in turn has long-term effects on global climate.

Learning Module #2 – Climate Change: Increase in Average Global Temperature

Indicated by the success of the behavior over time graph activity, this activity would satisfy the ILSS. The students were able to describe changes in the earth's climate and identify the relationship between CO_2 and temperature, which further reinforced the idea that human activities have an effect on climate change. Additionally, the students succeeded in predicting future climate trends based on past records.

Learning Module #3 – Climate Change: Effects on Lake Michigan

Although this activity was not as successful as the others in terms of full student participation and comprehension, this activity would be able to satisfy the ILSS to an extent. Some students were able to predict and describe what can happen to organisms when climate change affects organisms' habitats and availability of resources from changes in precipitation and temperature.

Question 2: Does the use of a systems thinking pedagogy provide insights and understanding in fourth grade students that would not be achieved otherwise?

In order to explore this question, I analyzed whether some of the resulting trends from the Waters Foundation's five years of "Collaborative Action Research" (discussed in Chapter 1) were apparent in my case study. One of the purposes for the Waters research program is to "begin to develop and collect evidence that describes the benefits of systems thinking and dynamic modeling on student learning" (Waters Foundation, 2010a). The main observation during my pilot study was the verbal and physical engagement of the students. According Collaborative Action Research, systems thinking increases engagement and motivation (Waters Foundation, 2010a). The students were not just listening to a lecture and taking notes. In fact, no notes were taken. The first and third activities brought the students out of their chairs. *They* were part of the lesson. The second activity, although seated, spurred discussion as each student began to connect the dots on their own Behavior over Time Graph (BOTG). Even though they were not physically recording any information in a notebook, the active engagement of the students still allowed for the attainment of the objectives.

BOTGs, according to Waters Foundation (2010b), help students visually describe changes over time. This was apparent during the second exercise, when students created their own BOTG of global temperature change. Before the exercise, there was no mention of the average global temperature increasing. The students were able to deduce this themselves as they plotted the points and connected the dots. They were able to discover and learn something on their own. This confirms the statement by The Creative Learning Exchange (2002) that systems thinking makes learning more learner-centered. Additionally, the students were able to deduce through the role-playing game in the first activity that CO_2 levels in the atmosphere are increasing without any mention by me.

Causal Loop Diagrams (CLDs) have been shown to help students identify cause and effect connections and feedback relationships within a system (Waters Foundation, 2010b). The CLDs developed in the third activity did enable the students to properly describe the simplified healthy Lake Michigan ecosystem. By adding new, harmful elements to the CLD and the web activity, some were able to describe how the healthy system would eventually collapse. Even though they were not introduced to or used terms such as balancing or reinforcing feedback, they correctly described the dynamics of a reinforcing feedback loop in the context of this problem.

Some of the habits of a systems thinker were apparent to an extent during the implementation of the case study; however, these "habits" do take time to develop, so it was not expected for the habits to fully manifest during these few activities. That is accomplished through more exposure to systems thinking activities and vocabulary. A student who has experience with systems thinking methodology should be able to apply these "habits" in many scenarios. In this case, the "habits" are more just extra learning objectives. In the pilot study, the students o*bserved how elements within systems change over time, generating patterns and trends* through their understanding of how atmospheric CO_2 and average global temperature are changing over time and their ability to form temperature and various CO_2 trends. The students were able to *see themselves as part of the system* when they recognized the place of humans in the climate change system in Learning Module #1. They correctly described an increase in atmospheric CO_2 as a result of anthropogenic activities. The students *looked for connections among elements in a system* and *identified the circular nature of complex cause and effect* when they succeeded to make and understand the connections between CO_2 and temperature in Learning Module #2, and among the elements in the Lake Michigan scenario of Learning Module #3. Although atmospheric CO_2 is a stock, the actual concept of stocks was not discussed; therefore, the ability for students to actually identify elements as stocks and flows is not probable. However, the students did understand how a stock works, as demonstrated with the bathtub scenario in Learning Module #1, *describing how things accumulate or diminish over time (stock and flow dynamics)*. The students were not able to completely *see the whole, or the big picture*. This is discussed further in the concluding section of this chapter.

Discussion

External Factors that Affected the Outcomes

It should be noted that this program was implemented in the middle of the summer; many of the students had not seen each other since early June. Although I had worked with some of the students previously for a science report, others did not know me. The students were also in an informal educational setting – the home of one of the students. These factors may have created some distraction. Furthermore, many had not opened a school text-book since early June. However, the students still put forth significant effort and were eager to learn.

Another aspect to consider concerns a small amount of "help" received among the students during the activities. Since the atmosphere was purposefully relaxed and all eight students were sitting together, they inevitably did talk with one another. However, it was observed that most students responded or acted on their own accord, with discussion amongst each other usually happening toward the end of each activity.

Limitations of the Findings from this Study

There were some constraints in the logistics of the implementation of the case study. First, there was no control group for this study. Hence, we have no basis for comparing student learning observed here to other curricula or pedagogical methods that do not rely on systems thinking. This could be done in future studies by comparing a class that uses these learning modules to a class that is instructed through a different method, such as a basic lecture. Would the students who learned through a different method have the same results as discussed at the beginning of this chapter? Although I did observe that these learning modules made learning active and enjoyable for the students, it is difficult to fully determine if they gained further insight and understanding without a control to make a comparison.

It may also be prudent to test the knowledge retention from the two different learning methods. Do the hands-on and visual aspects of systems thinking tools deliver greater knowledge retention than a basic lecture? Would students be able to answer the same assessment questions one month, or even longer, after the lessons?

Without a proper exam that tests the achievement of Illinois Learning Standards for Science, it is not definite that the learning modules achieve the Standards. However, the learning objectives, which were based on the Standards, were achieved through the learning modules.

Finally, the limited duration of the study, and the fact that it involved only a single, 2-hour session with students, brings into question the long-term benefits from the approach used here. While this does not negate the potential for developing systems thinking habits of mind, this study provides no basis for assessing such long-term impacts. Only a longitudinal study in which students are tracked and assessed through time and across multiple learning experiences could provide such evidence.

Did Systems Thinking Deliver What I Expected?

My main concern before implementing the learning modules was that the some of the activities in the learning modules would be too advanced. In addition, these students have had no previous exposure to systems thinking. Each learning module as a separate unit did deliver what I expected in terms of my two main goals of meeting the learning objectives and actively engaging the students. The students were physically and verbally engaged, laughing, smiling, and making observations on their own. Even with different learning styles, no student appeared to struggle more than another.

Climate change is not a simple topic to grasp, and certainly not something that can be fully grasped in two hours. Concentrating each activity on an aspect of climate change helped students explore this complex subject in manageable pieces.

However, there were some disappointments, as well. The students did not fully grasp of the concept of how CO_2 and other greenhouse gases (GHGs) trap heat. Furthermore, the comprehension of the entire picture – the simplified steps of how climate change works – was not achieved. I will discuss each of these separately below.

How CO_2 and other GHGs work to trap heat was not a focus of any activity, since it is not part of ILSS for fourth grade. This was explained through lecture points following the Learning Module #2 activity. Many of the students were able to make the connection between CO_2 and temperature – that the temperature is rising because CO_2 is rising – when with BOTGs. However, when verbally asked during the next activity how the temperature was rising, only one student (who had prior knowledge on this concept) had an answer. There can be multiple explanations for this lack of understanding. One could be that the concept of GHGs trapping heat is beyond the scope of knowledge for this age group. Just knowing that there is a direct correlation between CO_2 and temperature, but not the *why*, may be the extent of their understanding. Burnout and attention-loss by this time during the program could also be a factor. Also, this concept was taught using a more traditional lecture-based format. As previously stated, the visual and interactive tools of systems thinking did prove to generate an understanding of the other concepts that were covered. It is possible that, had a more active, systems-based approach been used to teach this particular concept, the student understandings might have improved

Capra (1998) states that systems thinking allows students to think in terms of relationships, connectedness, and context. The comprehension of the entire picture – the simplified steps of how climate change works – was not fully achieved by the end of this two-hour session. By the end of the program, the students were only able to verbally discuss climate change in short, two- to three-variable cause and effect scenarios. During the third and final activity, I asked the students about polar bears. Responses were short – one cause and one effect. When prompted to expand, the answers were, again, just simple cause and effect. When asked what was happing to CO_2, the students were not able to respond right away. I had to refer them back to the activities that we had done earlier. It was as if they had forgotten about the other activities, which they had mastered so well. I asked what causes the ice to melt. Again, it took some prompts and hints for the students to mention the connection between CO_2/GHGs and temperature.

The same factors can be considered for the inability to make these connections as with the lack of full understanding on how CO_2 and other GHGs work. Being able to make a simplified, step-wise summary of climate change, in the proper order, is probably too advanced for this age group. It would be especially difficult for them to make such connections after focusing and working for an hour and a half on the previous activities. By the third activity, it was noted that the students' focus had been lost. There also was no concluding activity that tied everything together. The students were expected to remember what they had learned from each activity, while learning a new concept and participating in a new activity. There was no time allowed for the knowledge to just absorb. The short, two-hour time period may not have allowed the students to make larger connections.

Suggestions for Further Research

Although these students were a good representation of the student body from St. Luke School, they do not represent other students that would be in fourth grade classes from other schools in Illinois. These students, as described in Chapter 3, come from similar middle to upper-middle class households with both parents, and have high expectations for education and learning. The students at St. Luke School test in the top quartile on the TerraNova National Achievement Test. The 2009-2010 fourth grade class (from which the participating students were drawn) received a median national average of 85 in science; therefore, 100 percent of those fourth grade students exceeded the national average in the subject area of science. Would these and other systems thinking lessons be successful with those students who test below the National average? Could systems thinking actually aid in boosting the scores of those students who continue to test below the National average with other more traditional teaching methods?

In general, there is a need for more peer-reviewed, published literature on the benefits of systems thinking, specifically whether learning through systems thinking tools aids in learning the subject material. This has been done by Plate (2006 & 2010) in his studies on the understanding of complex ecological systems, comparing students with a systems thinking background to those without a systems thinking background. However, this study used middle school and undergraduate students. Research should also be done on the benefits of systems thinking in elementary education. Other studies have focused on the development systems thinking skills, not on the success of using systems thinking to teach a specific subject (Assaraf & Orion, 2004). Additionally, there are no published, peer-reviewed results on the Waters Foundation's Collaborative Action Research, and the available information is minimal and not grade- or age-specific. I think one of the reasons for the lack of systems thinking in standards-based education, and in environmental education, is due to the absence of research in the area. The research thus far on the school systems that apply systems thinking is anecdotal. Education researchers can compare these schools to others that do not apply systems thinking. More research on the benefits and success of utilizing systems thinking tools would produce more leverage for its use in academia.

Although there are a few systems thinking lessons available that do convey environmental concepts, this can be expanded. Whether a teacher wants to instill knowledge on an environmental concept or on a systems thinking concept, environmental topics are inherently full of systems – systems thinking tools can be applied to instruct on the environmental concept, or an environmental topic can be used as an example to instruct on systems thinking. Especially in an era where humans are increasingly becoming a part of environmental systems, positively or negatively, there is much to learn about how humans can affect systems, or in general, how systems can be affected by outside influences. I do believe in systems thinking as an important skill set for today's students, and believe that education on environmental topics can benefit from it.

Lessons Learned: Improvements to the Case Study

If this program was to be implemented again, and improvements made based the observations discussed, I would spread the program over at least one week, with one day for each concept-based activity. One hour could be spent on each concept-based activity, which would allow for more in-depth discussion, questioning, and interaction with the students. One week would allow for more concepts and activities to be incorporated into the program to deepen the understanding of each concept. I would also incorporate an activity that teaches how CO_2 and other GHGs trap heat, to hopefully establish a better understanding of this concept. Two examples on how this could be done are explained below. On the last day, I would review all the concepts and remind the students of the activities that were performed. This would hopefully aid in connecting all of the learning modules and in seeing the 'big picture.' Reading books and/or watching instructional videos on climate change may also help the students see/hear what they have learned in one cohesive entity.

In order to explain that CO_2 and other GHGs trap heat, I would have the students play a game of tag. Before the game, it would be explained that GHGs trap the heat from the sun that is reflected by the earth – without GHGs, the earth would be an average 60°F cooler! It may be wise to draw a simple diagram of this, leaving the actual science of how it works for later learning at a higher grade. The first round of the game would include about one-fourth of the students as CO_2/GHG molecules, and the remainder as heat. The object of the game would be for the CO_2/GHG molecules to capture the heat. Each 'heat' that is captured would equal one point. The number of points would be recorded. After the first round, the number of CO_2/GHG molecules would be increased to half of the students. Each 'heat' that is captured this time would equal five points. The number of points would be recorded. This would illustrate that when more CO_2 was added to the game, more heat was trapped. The idea for the points is to make sure that each student is participating throughout the game. Since I would not want to have students sit-out during the first round to allow for the amount of heat trapped increase during the second round, the point system would still provide for that increase.

Another experiment that could be done to demonstrate how CO_2 and other GHGs trap heat is to record the increasing temperature of a glass of water on a windowsill in the sun. This could be done if there was no out-door space or a gym for the tag game, or if a subdued activity is more appropriate. As the cup of water sits in the window sill, the temperature would be periodically taken and recorded; the recorded temperatures would be plotted on a BOTG. The water would be acting like the CO_2/GHG molecules trapping the heat from the sun.

APPENDIX 1

Table 1: The Waters Foundation's Habits of a Systems Thinker

1. Seeks to understand the big picture
2. Observes how elements within systems changes over time, generating patterns and trends
3. Recognizes that a system's structure generates its behavior
4. Identifies the circular nature of complex cause and effect relationships
5. Changes perspectives to increase understanding
6. Surfaces and tests assumptions
7. Considers an issue fully and resists the urge to come to a quick conclusion
8. Considers how mental models affect current reality and the future
9. Uses understanding of system structure to identify possible leverage actions
10. Considers both short and long-term consequences of actions
11. Finds where unintended consequences emerge
12. Recognizes the impact of time delays when exploring cause and effect relationships
13. Checks results and changes actions if needed: "successive approximation" (Waters Foundation, 2010h)

Table 2: Linda Booth Sweeney's Habits of a Systems Thinker

1. Sees the Whole
2. Looks for Connections
3. Pays attention to Boundaries
4. Changes Perspective
5. Looks for Stocks
6. Challenges Mental Models
7. Anticipates Unintended Consequences
8. Looks for Change over Time
9. Sees Self as Part of the System
10. Embraces Ambiguity
11. Finds Leverage
12. Watches for Win/Lose Attitudes

APPENDIX 2

The Illinois Learning Standards for Science

The Illinois Learning Standards for Science (ILSS) "describe '*what'* students should know and be able to do in grades K-12" (Illinois State Board of Education, 2002). The ILSS consists of a hierarchical system with increasing specificity to improve the quality of classroom science education (Illinois State Board of Education, 2002). The first layer in this system is the three goals: Goal 11 = inquiry and technological design; Goal 12 – content areas of the life, physical, and earth/space science; and Goal 13 = science, technology, and society. The goals are general statements of what students must know for successful learning achievement. These goals are further broken into ten learning standards: two in Goal 11, six in Goal 12, and two in Goal 13 [11 A&B; 12 A-F; and 13 A&B]. The learning standards are specific statements of necessary science knowledge or skills. The next layer under the learning standards is the benchmarks, denoted by numbers (e.g. 1, 2, …). The benchmarks are indicators of student achievement. The Performance Descriptors are the last layer under the benchmarks, denoted in this thesis with lower-case letters (e.g. a, b, …).

The learning for this thesis were developed around the Performance Descriptors. The Performance Descriptors are "knowledge and skills that students are to perform at various stages of educational development" (Illinois State Board of Education, 2002). The primary function of the Performance Descriptors is "to provide educators with necessary tools to continue the quest of improving the quality of science education throughout Illinois" (Illinois State Board of Education, 2002).There are ten developmental stages (Stages A-J) that provide information on the physiological and intellectual development of students throughout their education (Illinois State Board of Education, 2002). The Performance Descriptors were written by: teachers, curriculum writers, consultants, professors, and governmental science center directors, and reviewed by teams of Illinois teachers. The actual Performance Descriptors chosen for the learning modules are listed below.

The Performance Descriptors

Learning Module #1 – 12E.D.2.b; 12E.D.2.c

Learning Module #2 – 12E.D.2.a; 12E.D.2.b; 12E.D.2.c; 12E.E.2.b

Learning Module #3 – 12B.C.2.c; 12B.D.1.c; 12B.E.2.b; 12E.D.2.b

12B: Students who meet the standard know and apply concepts that describe how living things interact with each other and with their environment.

C.2.c. Apply scientific inquiries or technological designs to examine the interdependence of organisms in ecosystems, predicting what can happen to organisms if they lose different environmental resources or ecologically related groups of organisms.

D.1.c. Apply scientific inquiries or technological designs to examine relationships among organisms in their environment, considering habitat changes due to changes in moisture, temperature, or seasons.

E.2.b. Apply scientific inquiries or technological designs to explain competitive, adaptive, and survival potential in different or local ecosystems, explaining biotic or abiotic factors which threaten health or survival or populations of species.

12E: Students who meet the standard know and apply concepts that describe the features and processes of Earth and its resources.

D.2.a. Apply scientific inquiries of technological designs to analyze the natural weather patterns, describing short- to long-term changes in earth's climate.

D.2.b. Apply scientific inquiries of technological designs to analyze the natural weather patterns, suggesting possible causes of climatic changes and effects on biotic communities.

D.2.c. Apply scientific inquiries of technological designs to analyze the natural weather patterns, evaluating evidence that human activities have long-term effects on global climate.

E.2.b. Apply scientific inquiries or technological designs to analyze weather and climatic conditions, projecting future trends based on past and current records.

APPENDIX 3

This section contains these materials in the following order: the ‘prologue’ to the learning modules, the three learning modules with assessment sheets, and the ‘wrap-up’ to the learning modules. This ‘package’ of materials is prepared for use in a formal or informal education environment.

A Prologue to the Climate Change Unit

What this unit does:

This unit uses system thinking tools and activities to explain: what is happening to the global climate, why it is happening, and how these changes may affect the ecosystem of Lake Michigan. Each lesson is linked to Illinois Science Performance Descriptors for Grade 4. There are three separate activities that should be used together and taught in this order:

1. Climate Change: Increase in CO_2 in the Atmosphere
2. Climate Change: Increase in Average Global Temperature
3. Climate Change: Effects on Lake Michigan

Each activity builds upon the previous activity, considering both global and local contexts. After all three activities are complete, look at the “Wrap-up” section. This should be treated as important as the actual activities.

Before the teaching begins, become familiar with the “Overview of Climate Change.” This is a simplified explanation that should be referenced throughout the activities to include relevant information when necessary. Vocabulary words and a short section of background information relating to the activity are provided for each activity. Resources are also provided at the end of each activity.

Teacher preparation:

Each student should have his or her own folder, or bound notebook, with all the materials in proper order that are needed for this unit. All of the vocabulary terms should be compiled to one page and placed in the folder. Any additional relevant materials, such as articles and fact-sheets, can also be placed in the folders.

Adaptations:

As with any lesson, adapt the lesson based on your location or your creativity. Give the students costumes when they are role-playing, add stories, movies, or songs. These plans are just suggestions; mold them to make them your own! These activities can be performed with a variety of classroom sizes. Scale the activities appropriately to make sure that all students are participating.

Assessment:

Assessment sheets are attached to each activity. Do not treat the assessments like a test; they are just a part of the activity! Visual assessments should be made throughout all activities.

Overview of Climate Change:

Over the past century, the earth has warmed by about 1.4°F. In the next 50-100 years, the average temperature of the earth may increase by another 2°- 9°F. This average increase in temperature is what we refer to as 'global warming.' This global warming brings about changes in the earth's weather patterns, which we call 'climate change.' Although the earth's climate has been changing since it was formed, this change is at a much faster rate because of some human practices. Since the Industrial Revolution over 200 years ago, the burning of fossil fuels, further population growth, and deforestation has contributed to an increase of greenhouse gases in the atmosphere. When sunlight enters the atmosphere, some of the sun's energy is absorbed by land, water, and living organisms, while some of the energy is sent back to atmosphere and trapped by the greenhouse gases. Thus, the more greenhouse gases in the atmosphere, the more energy from the sun is trapped, and the warmer the temperature. Greenhouse gases are produced from: oil and coal burning power plants that provide our electricity, automobiles, factories, landfills, and even animals (i.e. cattle farms)! Scientists do not know exactly what my happen with climate change, and changes will be different in different parts of the world. Some places may experience more rainfall than normal, while others will experience less. Some places will become hotter, while others will become colder. Some bodies of water will contain less water, while others will contain more. These changes will impact both humans and wildlife.

References:

US EPA ‘Climate Change Kids Site’ - http://www.epa.gov/climatechange/kids/

Wisconsin DNR ‘Global Warming is Hot Stuff!’ - http://dnr.wi.gov/org/caer/ce/eek/earth/air/global.htm

OneWorld.net ‘Hot Earth’ - http://tiki.oneworld.net/global_warming/climate_home.html

ClimateChangeEducation.org ‘GlobalWarmingKids.net’ - http://globalwarmingkids.net/

Pew Center ‘Global Climate Change’ - http://www.pewclimate.org/global-warming-basics

Learning Module #1 – Climate Change: Increase in CO_2 in the Atmosphere

Note: An overview exercise on BOTGs, 'Change Over Time,' can be found on the Waters Foundation website.

Level: Grade 4

Illinois standards: 12E.D.2.b; 12E.D.2.c

Habits of a systems thinker: Observe how elements within systems change over time; sees self as part of system; describe how things accumulate or diminish over time (stock and flow dynamics)

Systems thinking concept: Change over time, balancing feedback, stocks and flows

Systems thinking tools: Bathtub analogy, behavior over time graph (BOTG), experiential exercise

Objectives: Identify some human activities that affect atmospheric CO_2 and explain how the activities affect it. Use the bathtub analogy to predict what will happen to CO_2 if emissions are continued at the same level, if emissions are reduced but not below the rates at which CO_2 is removed from the atmosphere, or if emissions are reduced below the levels at which CO_2 is removed from the atmosphere. Match BOTGs of CO_2 trends with the appropriate bathtub analogy scenario.

Summary: Use a role-playing game, the bathtub analogy, and BOTGs to visually illustrate the increase in CO_2 in the earth's atmosphere over time.

Setting: Classroom or the outdoors

Length/Time: 30 minutes

Vocabulary words:

- Atmosphere = thin layer of gases surrounding the earth; protects life by absorbing ultraviolet rays from the sun and warms the earth through the greenhouse effect
- Greenhouse gases (GHGs) = gases in the atmosphere trap energy from the sun (Examples: CO_2, NO_x, CH_4, water vapor)
- Fossil fuels = fuels (examples: coal, oil, natural gas) that result from the compression of ancient plant and animal life formed over millions of years

Materials:

- Large writing surface (e.g. blackboard, whiteboard, easel, etc.)
- A number of objects to represent CO_2 (e.g. Nerf balls, bean bags, etc. The number will depend on the size of the group. Suggestion: three times the number of objects as students)
- Objects representing: plants, animals, factories, and cars (e.g. a picture of a bird, a large leaf from a tree, etc. The number of objects should equal the number of students. The number of plants must equal the number of animals.)
- Masking tape, chalk, or another medium to make a circle on the floor
- Bathtub diagram and pictures representing: plants, animals, factories, and cars
- Writing utensils

Background:

Since the Industrial Revolution over 200 years ago, the burning of fossil fuels, further population growth, and deforestation has contributed to an increase of greenhouse gases in the atmosphere. GHGs include CO_2, NO_x, CH_4, and water vapor, and are produced through the burning of fossil fuels. Fossil fuels, such as oil and coal, are burned when we drive automobiles, produce electricity, and make products in factories. GHGs are also naturally found in the earth's atmosphere.

Outline/Procedures:

1. Explain that in a minute we will be playing a game, but first we need to review a few things.
2. Ask the students to tell what they know about carbon dioxide (CO_2). At this grade level, they should understand that CO_2 is produced when humans breathe, and plants use it to grow and make oxygen. Explain that CO_2, along with other gases like it, is also produced from activities that burn fossil fuels such as: driving automobiles, producing electricity, and making products in factories. Define fossil fuels. We call these gases greenhouse gases (GHGs). Define greenhouse gases.
3. Have the students gather together. Make sure that nothing is in the immediate vicinity that any of the students can trip over/run into while they are playing.
4. Mark a circle on the floor (chalk, tape, etc). Place 1/3 of the objects representing CO_2 together in the circle. The remainder should be placed out of the circle. Take one of the objects and tell the students to pretend that it represents CO_2, while the circle is the atmosphere. Have the students count how many objects, or CO_2's, are present in the atmosphere. Write this on the board. Tell the students that this represents a 'healthy' atmosphere, before humans affected the atmosphere.
   a. Give each student an object that represents the role they are playing (plant, animal, factory, car). Tell the students that they are to pretend to be the object they were given. Explain the roles.
      i. Plant: takes CO_2 out of the atmosphere
      ii. Animal: puts CO_2 into the atmosphere
      iii. Factory: puts CO_2 into the atmosphere
      iv. Car: puts CO_2 into the atmosphere
   b. The first round of the game will just involve the plants and the animals. This is a 'healthy' atmosphere, before factories and cars were created.
   c. Have the 'plant(s)' remove a CO_2 from the atmosphere and an 'animal(s)' put a CO_2 into the atmosphere. Repeat this a few times. Ask the students to count how many objects are in the atmosphere. Write this on the board. They should notice that the number has not changed. The plants and the animals have a relationship that *balance* the CO_2 in the atmosphere.

d. Now tell the factory(ies) and car(s) to join the game. The factory(ies) and car(s) will add a CO_2 to the atmosphere, while the plant(s) and animal(s) continue to make their balancing exchange.

e. After all of the objects have been placed into the atmosphere, have the students once again count the objects in the atmosphere. Write the number on the board. They should notice that the number has now increased.

5. Have a large picture of a bathtub that you can display. Hang this in an area where all the students can see. Explain how the atmosphere is like the bathtub and the CO_2 is like the water. Ask the students the questions below. For questions b, c, e, and f, ask the students to help you draw a BOTG that represents what is happening to the water in the bathtub (CO_2 levels over time). Draw the simple BOTG next to the bathtub diagram:

   a. Which roles that you played in the game (plants, animals, cars, factories) are part of the 'faucet,' adding CO_2 to the atmosphere, and the 'drain,' removing CO_2 from the atmosphere? – the animals, cars, and factories are the faucet and plants are the drain. Place pictures of these onto the bathtub diagram in the proper locations.

   b. What happens to the bathtub when only animals are part of the faucet? – The water level in the bathtub remains the same. Plants and animals create a balance of CO_2 in the atmosphere. The BOTG is a straight line.

   c. What happens if the faucet runs faster than what the drain can empty? Add more animals, cars, and factories than plants to the diagram. – The bathtub would overflow. The BOTG is an increasing line.

   d. Based on the diagram, what kinds of things can be done to increase the amount of CO_2 taken from the atmosphere? – Increase the amount of plants. How can this be done?

   e. If we reduced the amount of CO_2 that cars and factories put into the atmosphere, but there was still more CO_2 being put in to the atmosphere than plants could remove (remove some cars and factories from the diagram, but leave more than the number of plants), how would CO_2 in the atmosphere change over time? - CO_2 would continue to increase, but not as rapidly. Water would continue to flow into the bathtub and fill it until it overflowed. The BOTG is an increasing line, with a gentler slope than in 'c.'

f. If we reduced the amount of CO_2 from cars and factories so much that plants were removing more CO_2 from the atmosphere than what the cars and factories were putting into the atmosphere, what would happen? – CO_2 in the atmosphere would decrease, but it would take a long time. The water level in the bathtub would decrease, but it would take a long time for the bathtub to empty. The BOTG is a gently decreasing line.

Assessment: See '**Worksheet – Climate Change: Increase in CO_2 in the Atmosphere'**

Teacher preparation:

- Clear the classroom so there is a large space to play the game, or choose a favorable outdoor location
- Prepare the objects that the children will use for the role-playing (plant, animal, factory, car). A suggestion is to use local examples. Here are some suggestions for Illinois:
  - Plants: white oak, violet, big bluestem
  - Animals: monarch butterfly, white-tailed deer, northern cardinal, bluegill
  - Factories: Deere & Co., Motorola Inc., Caterpillar Inc., Archer Daniels Midland Co.
  - Cars: Mitsubishi, Dodge, Jeep, Ford
- Prepare the pictures (plants, animals, cars, factories) that will be placed on the bathtub diagram
- Print a bathtub diagram

Resources:

The Waters Foundation 'Causal Loop Diagrams of Global Warming' - http://www.watersfoundation.org/index.cfm?fuseaction=content.display&id=164

US EPA 'Climate Change Kids Site' - http://www.epa.gov/climatechange/kids/

Wisconsin DNR 'Global Warming is Hot Stuff!' -
http://dnr.wi.gov/org/caer/ce/eek/earth/air/global.htm

OneWorld.net 'Hot Earth' - http://tiki.oneworld.net/global_warming/climate_home.html

ClimateChangeEducation.org 'GlobalWarmingKids.net' - http://globalwarmingkids.net/

Pew Center 'Global Climate Change' - http://www.pewclimate.org/global-warming-basic

Worksheet – Climate Change: Increase in CO_2 in the Atmosphere

Match the following statements with the graphs on the next page:

A. Before cars and factories, plants and animals controlled the amount of CO_2 in the atmosphere.

B. When humans began to use cars, and produce electricity and things in factories, CO_2 in the atmosphere increased.

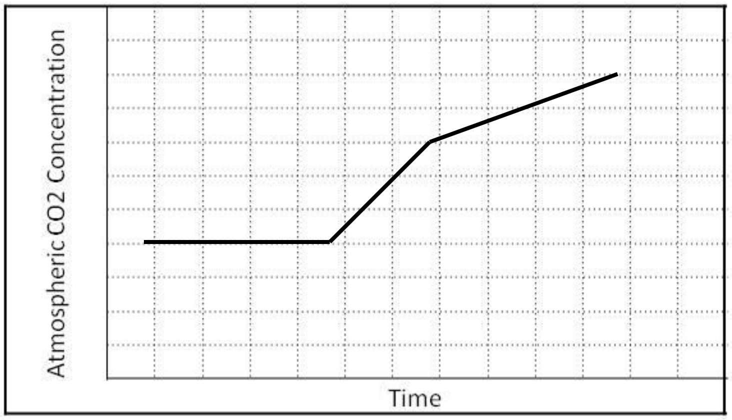
C. If we drive less and use power more efficiently, less CO_2 will be added to the atmosphere than what we are adding now.

Answers:

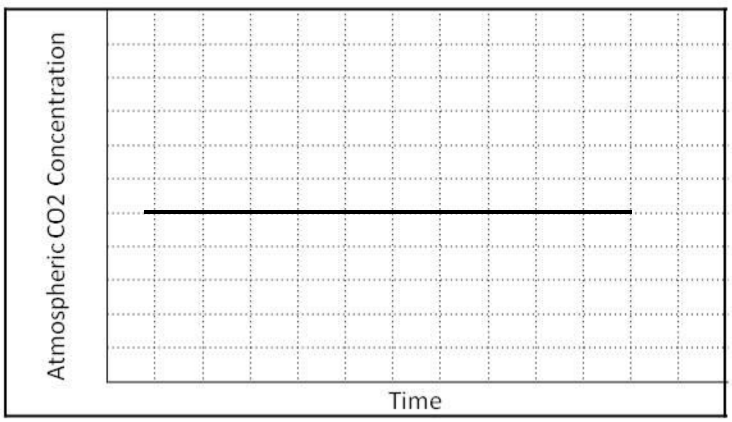
Statement _____ and Graph _____

Statement _____ and Graph_____

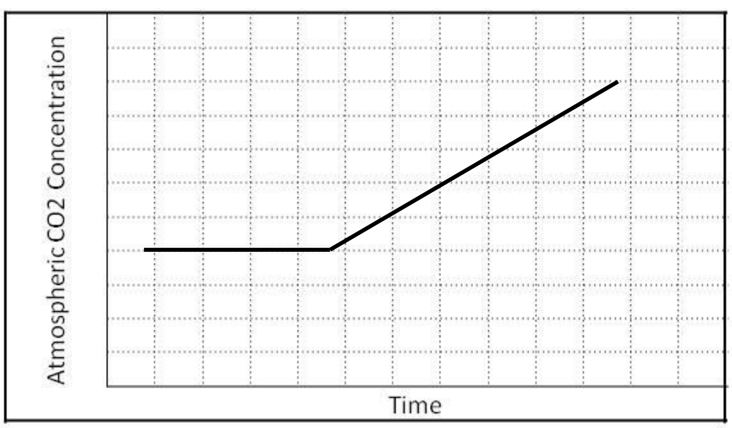
Statement _____ and Graph _____



Atmospheric CO2 Concentration
Time



Atmospheric CO2 Concentration
Time



Atmospheric CO2 Concentration
Time

Learning Module #2 – Climate Change: Increase in Average Global Temperature

Note: An overview exercise on BOTGs, 'Change Over Time,' can be found on the Waters Foundation website.

Level: Grade 4

Illinois standards: 12E.D.2.a; 12E.D.2.b; 12E.D.2.c; 12E.E.2.b

Prerequisite: Climate Change: Increase in CO_2 in the Atmosphere

Habits of a systems thinker: Observe how elements within systems change over time, generating patterns and trends; looks for connections among elements in a system

Systems thinking concepts: Change over time

Systems thinking tool: Behavior over time graph (BOTG)

Objectives: Create a BOTG of global temperature change over time and describe the graph in words. Analyze a BOTG of global temperature change and CO_2 trends and explain what is happening to temperature and why. Analyze a BOTG of global temperature change and CO_2 trends and predict that global temperature will continue to increase with a continued increase in CO_2. Suggest some effects that this increase in temperature may have on the environment.

Summary: Use a BOTG to illustrate how the global temperature is increasing.

Setting: Classroom or the outdoors

Length/Time: 20 minutes

Vocabulary words:

- Weather = the state of the atmosphere at a given time and place, regarding variables such as temperature, moisture, wind velocity, and barometric pressure climate; what is happening outside at a given time and place
- Climate = long-term average (usually 30 years) of a region's weather patterns
- Climate change = change in long-term weather patterns (examples: warmer or colder temperatures, increase or decrease in annual precipitation)
- Global warming = average increase in the earth's temperature, which causes changes in climate
- Greenhouse effect = the higher temperature that earth experiences because greenhouse gases in the atmosphere trap energy from the sun

Materials:

- Templates for *Temperature Change over Time* graph
- *Global Surface Temperature Trends* graph
- Writing utensils
- Rulers

Background:

The earth is experiencing an increase in average temperature, which is known as global warming. Since 1850, the earth has warmed by about 1.4°F. It is predicted that within the next 50-100 years, the average global temperature will increase by another 2° - 9°F. The average increase in global temperature that the earth is experiencing is due to an increase in greenhouse gases (GHGs) in the earth's atmosphere. GHGs are naturally found in the earth's atmosphere. They keep the earth warm; without them the average temperature of the earth would be 60°F less than what it is now! When more GHGs are added to the atmosphere, they continue to do what they do best and heat the earth; therefore, the more GHGs in the atmosphere, the warmer the earth gets!

Outline/Procedures:

1. Ask the students to describe what the weather was like yesterday and today. Do any of them remember what it was like a few days ago? A few weeks or months ago?
2. Ask the students if they can define the word ‘climate.’ Define it (if necessary) and make sure they understand the difference between weather and climate. Give the students examples (e.g. compare the climate of Chicago to that of Orlando – Disney World). Explain that recently climate has been changing because of something called ‘climate change.’
3. Ask the students to take out the graph paper with the template titled *Temperature Change over Time*. Explain the template: *time (years)* on the x-axis, *temperature change (degrees F)* on the y-axis.
4. Have the students graph the following points in a behavior over time graph. Write these points on the board:
    a. 1865 – 0.0
    b. 1885 – 0.1
    c. 1945 – 0.4
    d. 1985 – 0.7
    e. 2005 – 1.4
    f. *Teacher Note:* The points were extracted from the *Global Surface Temperature Trends* graph.
5. What do the students notice about the temperature graph? Have them record their answer on the assessment sheet.
6. Show the ‘Global Surface Temperature Trends’ graph and mention how the graph was created by climate scientists. See if any of the students notice how the graph is not just increasing, but that there are also some periods where the temperature was decreasing. Explain that it is normal for the global temperature to fluctuate over time; however, overall the temperature trend is increasing.
7. Explain that this increase in global temperature is called ‘global warming.’ However, not all places all over the world will experience an increase in temperature. Some will experience a decrease in temperature. Mention that

precipitation levels will also change, increasing or decreasing depending on the location. Other changes to the climate will occur because of global warming. That is why we refer to the whole situation as 'climate change.'

Assessment: See '**Worksheet – Climate Change: Increase in Average Global Temperature**'

Wrap up:

1. Make sure the students are able to make the connection between CO_2 and temperature.
2. In order for the students to get a sense of how the greenhouse effect works, talk about an everyday example, such as sitting in a car with the windows up in the sun. Discuss how CO_2 and other GHGs work.

Teacher preparation:

- Create a template for the *Temperature Change over Time* graph
- Print the *Global Surface Temperature Trends* graph

Resources:

The Waters Foundation 'Change Over Time' - http://www.watersfoundation.org/index.cfm?fuseaction=content.display&id=58

US EPA 'Climate Change Kids Site' - http://www.epa.gov/climatechange/kids/

Wisconsin DNR 'Global Warming is Hot Stuff!' - http://dnr.wi.gov/org/caer/ce/eek/earth/air/global.htm

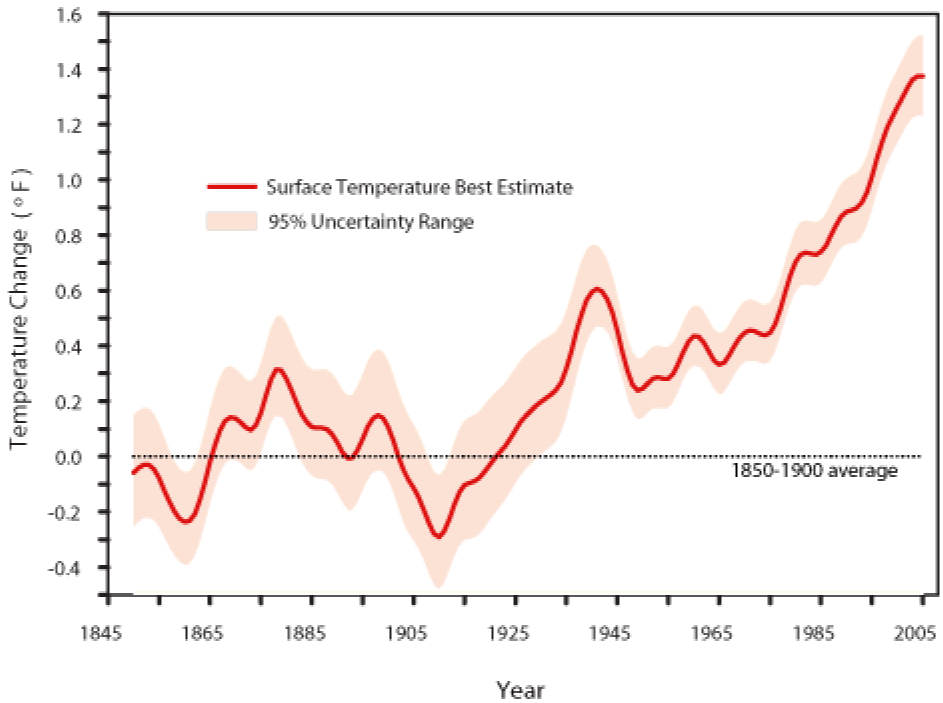
OneWorld.net 'Hot Earth' - http://tiki.oneworld.net/global_warming/climate_home.html

ClimateChangeEducation.org 'GlobalWarmingKids.net' - http://globalwarmingkids.net/

Pew Center 'Global Climate Change' - http://www.pewclimate.org/global-warming-basics

Global Surface Temperature Trends

1850 - 2005



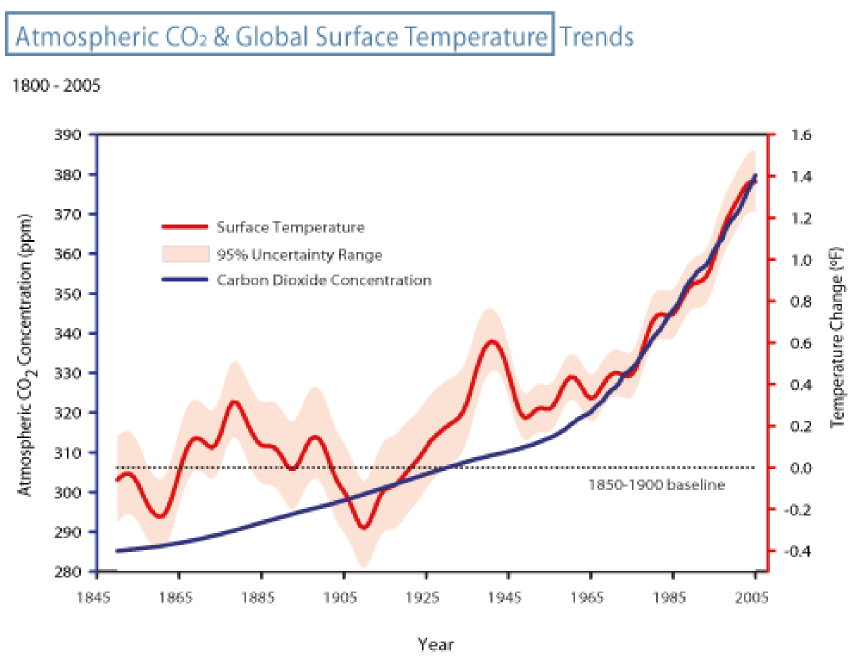
Data Source: Brohan, P., J. J. Kennedy, I. Haris, S. F. B. Tett, and P. D. Jones. 2006. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Journal of Geophysical Research 111: D12106, doi:10.1029/2003JA009974.

http://www.pewclimate.org/global-warmingbasics/facts_and_figures/temp_ghg_trends/temp.cfm

Worksheet – Climate Change: Increase in Average Global Temperature

Describe what is happening to temperature in the *Temperature Change over Time* graph.

Look at the graph below showing trends in the earth's temperature (wiggly red line) and the trends in the amount of CO_2 in the atmosphere (smooth blue line). If you met a visitor from another planet who wanted to know what this graph is saying, could you write a short story that explains what is happening to temperature and why?



Source of CO_2 Concentration data: Keeling, C.D. and T.P. Whorf. 2005. Atmospheric CO_2 records from sites in the SIO air sampling network. In Trends: A Compendium of Data on Global Change. Carbon Dioxide Information Analysis Center, Oak Ridge National Laboratory, U.S. DOE, Oak Ridge, Tenn., U.S.A.

Source of Temperature data: Brohan, P., J. J. Kennedy, I. Haris, S. F. B. Tett, and P.D. Jones. 2006. Uncertainty estimates in regional and global observed temperature changes: a new dataset from 1850. Journal of Geophysical Research 111: D12106, doi:10.1029/2003JA009974.

Based on the above graph, what do you think will happen in the future to the earth's temperature?

Suggest some possible effects that this temperature change may have on the environment.

Learning Module #3 – Climate Change: Effects on Lake Michigan

Note: Causal loop diagrams (CLDs) or connection circles can be used for this activity. An exercise for 6-12 grade using CLDs, 'Global Warming CLDs,' can be found on The Waters Foundation website. An exercise using connection circles, 'Keystone species in an Ecosystem Using Connection Circles to Tell the Story,' can be found on The Creative Learning Exchange website. The hands-on activity was adapted from the exercise 'Web of Life' in the ***Systems Thinking Playbook*** ***by Linda Booth Sweeney and Dennis Meadows.***

Level: Grade 4

Illinois standards: 12B.C.2.c; 12B.D.1.c; 12B.E.2.b; 12E.D.2.b

Habits of a systems thinker: Looks for connections among elements in a system; identifies the circular nature of complex cause and effect relationships; sees the whole, or the big picture

Systems thinking concepts: Interdependencies and feedbacks

Systems thinking tools: Causal loop diagrams (CLDs) or connection circles or, hands-on activity

Prerequisite: Climate Change: Increase in CO_2 in the Atmosphere; Climate Change: Increase in Average Global Temperature

Objectives: Use a CLD or connection circle to identify the relationships among organisms and their resources in their environment. Use a CLD or connection circle to predict and describe the effects of climate change on Lake Michigan that are due to habitat changes and loss of resources.

Summary: Use CLDs or connection circles and a hands-on activity to explain the possible effects of climate change on Lake Michigan.

Setting: Classroom or the outdoors

Length/Time: 30min

Vocabulary words:

- Runoff = water that is not absorbed by the soil and eventually makes it way to a water body (e.g. river, lake), carrying with it whatever it encounters along the way (e.g. soil, fertilizers, pesticides, oil)

Materials:

- 3 balls of yarn (or one ball cut into 3 long pieces)
- Objects representing: oxygen, fish, CO_2, plants, water temperature, ice cover, intense storms, water pollution (e.g. pictures, note cards with words or drawings on them)

Background:

In May 2008, the Healing Our Waters® - Great Lakes Coalition published a report titled "Great Lakes Restoration & the Threat of Global Warming" (Dempsey, Elder, & Scavia, 2008). The report summarizes the potential impacts that climate change may have on the Great Lakes. Contributions to this report were made by the Union of Concerned Scientists and the Ecological Society of America. Further resources were provided by the National Park Service, the Presidential Climate Action Project, the Brookings Institute, and many others. The report is a synthesis of the *likely* impacts warming temperatures will have on the Great Lakes; we cannot know the full extent of the impacts, we can only make predictions based on the best scientific knowledge available. Below are summarized some of the likely major ecological impacts described in that report.

Assuming global carbon emissions continue to grow at their current rates, the Great Lakes region is projected to have a temperature increase of 5.4 – 10.8°F relative to temperatures from 1961-1990. As a result, the growing season may start 15-35 days earlier and the first frost may arrive 35 days later. This temperature increase would cause lakes to warm, increasing evaporation, decreasing ice cover, and lowering water levels – Lake Michigan water levels can drop by three feet, one foot within the next century. Fish egg mortality would also result from a decrease in ice cover, lowering the strength of juvenile fish. As the length and timing of the seasons change, as noted above, the turnover rate would be affected. Turnover is the complete mixing of the lake water mass during the fall and winter as a result of temperature gradients in the water column. During this process, oxygen-rich surface water is brought to the depths, while nutrient-rich bottom water is brought to the surface. Changes in the timing of turnover events may reduce nutrient supplies to surface waters and lead to anoxic, or oxygen-devoid, bottom conditions. Toxic chemicals (PCBs and mercury) trapped in sediments would be released from the increased water temperatures and decreased water levels.

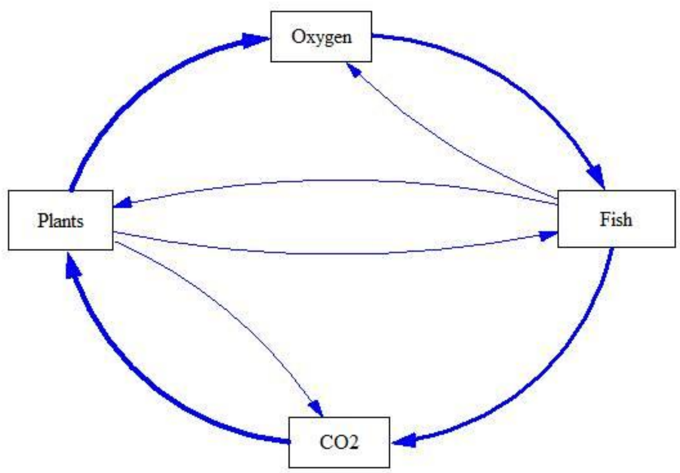
The region may also experience more intense storm events, eroding soil and increasing the runoff that transports the soil. Agricultural pollutants (nitrates, phosphorous, and pesticides) attached to sediment would be transported to waterways; sewage systems would reach their maximum and overflow. Beach closings and costs to maintain water quality goals, including our drinking water supply, would increase. Increased algal growth that sustains high concentrations of pathogenic bacteria would increase, posing harm to fish, birds, and humans. With all these changes, native species may lose habitat; invasive species find may find these habitats more suitable, out-competing native species. Some species may be able to re-locate and find more suitable habitat elsewhere, while others would not be able to survive.

Outline/Procedures:

1. By now, the students should understand that global temperature is increasing because of a human-induced increase in greenhouse gases (a phenomenon known

as climate change). They have been asked to brainstorm ideas on what can happen to ecosystems because of this.

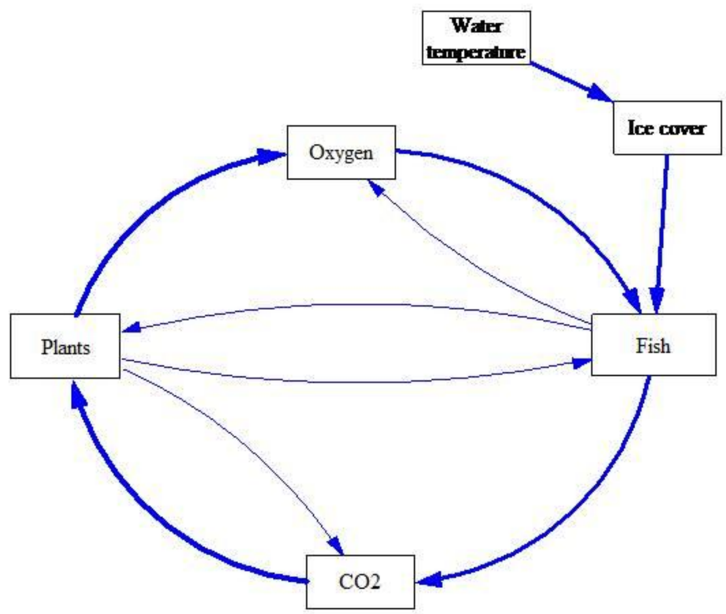
2. Most students should be familiar with what is happening to polar bears due to climate change. Read a story, show a video clip, or just tell them about it.
3. Climate change is affecting Lake Michigan as well, but before we can understand the effects, we need to know what a healthy ecosystem looks like.
4. Give four students an object representing the following variables: oxygen, fish, CO_2, and plants. Ask the students to gather in a circle.
    a. Have the students create the *Healthy Ecosystem* CLD.



    b. Give a ball of yarn to the student representing oxygen. Ask the students to make a healthy ecosystem by passing the ball of yarn in the proper order. Make sure that the 'oxygen' student holds onto the end of the yarn. Have another student or two draw the CLD that is being made on the board.
    c. Explain how the connections among the variables make it a healthy ecosystem. The outer circle is a reinforcing loop, meaning that as long as each element is healthy and happy, the whole system continues to be healthy and happy. However, if one of the elements begins to decline, the whole system can eventually collapse. The other loops are balancing feedback loops, which help maintain a healthy, stable ecosystem. Since those balancing feedback loops affect the larger reinforcing loop, if any of

the balancing feedbacks loops are upset, the whole system would be affected and possibly collapse.

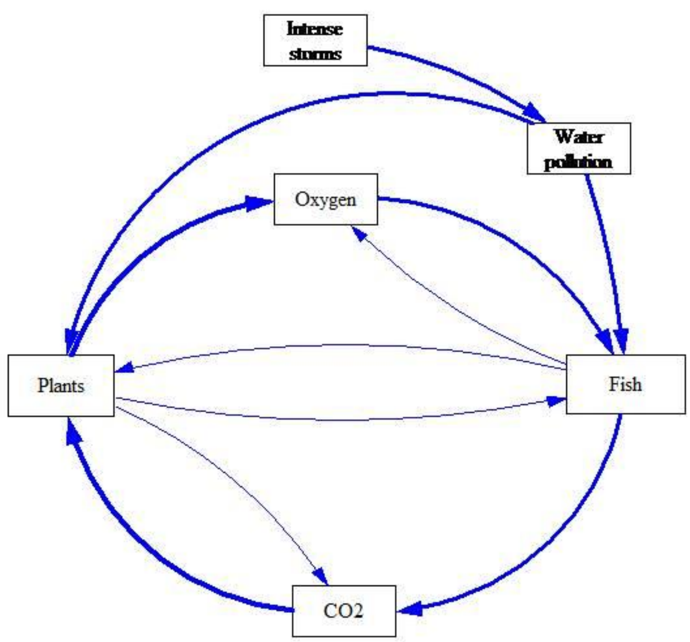
d. When the healthy ecosystem is complete, explain that climate change is causing the air temperature around Lake Michigan to increase, which in turn increases the temperature of the Lake. Incorporate ‘water temperature’ into the CLD (both in the ‘human circle’ and on the board). Explain how the water temperature will affect the amount of ice cover in the winter. Ask the students what they think will happen to the ice cover. Incorporate ‘ice cover’ into both CLDs. A ball of yarn should be given to the ‘water temperature student’ and passed to the ‘ice cover’ student. The ‘ice cover’ student should pass to the ‘fish student.’



e. What do the students think will happen to the fish because there is less ice cover? This may be a bit tricky, but just simply say that the fish need ice for the baby fish to grow properly; without a lot of ice, the baby fish cannot grow strong to become adult fish.

f. Ask the students if they can see what can happen to the circle when fish do not do well. Can they see that the effects of climate change have now made the reinforcing circle unhealthy? The circle is still reinforcing, but instead of being reinforcing in a good way, it is reinforcing in a bad way**.** When the fish have trouble surviving, the plants then have trouble surviving, and the pattern continues.

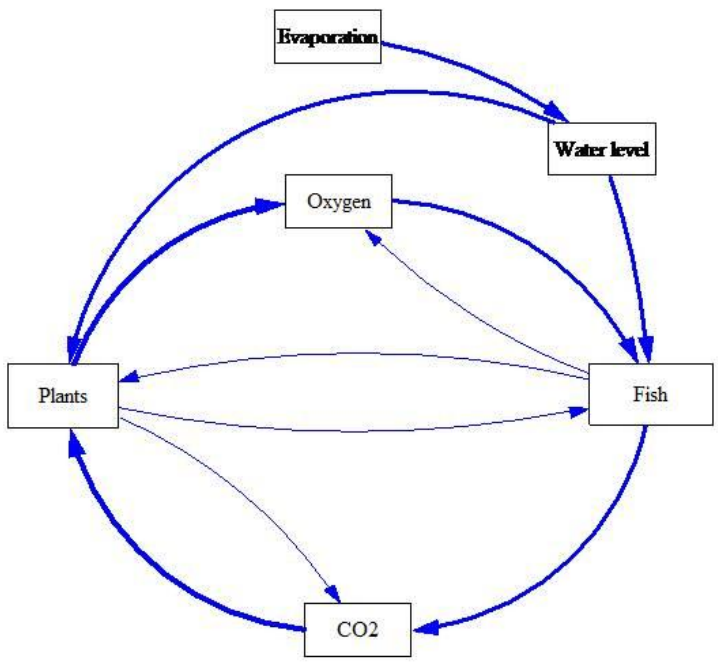
5. Now we are going to make another CLD with two new variables. Give each student an object that represents the following variables: oxygen, fish, CO_2, plants, intense storms, water pollution (depending on the number of students, have different students in the 'human circle' and others drawing on the board). Have another student or two draw the CLD being made on the board.
    a. Create the *Healthy ecosystem* CLD again. Explain that because of climate change, the area around Lake Michigan is going to have more intense storms. Give the 'intense storms' student a ball of yarn. The intense storms are going to create a lot of water that is going to wash pollution from farms and cities into the Lake. This is called runoff. Have the' intense storms' students pass ball of yarn to the 'water pollution' student.



    b. Ask the students to predict what may happen when the water pollution increases. Water pollution can harm both the fish and the plants, so two balls of yarn are needed to pass to both fish and plants. Can the students see how the effects from climate change alter the circle? The circle is still reinforcing, but instead of being reinforcing in a good way, it is reinforcing in a bad way**.** The fish have trouble surviving, which in turn affects the survival of the plants, and the pattern continues.

Assessment:

1. This assessment is a group assessment. Ask the students to help you draw a CLD with new variables. Begin with the original, *Healthy ecosystem* CLD. Ask them to add ‘evaporation’ and ‘water level’ to the CLD. Where would the arrows connect? How would it affect the ‘healthy’ ecosystem?



   a. Just as with the other CLDs, the evaporation variable is connected to the water level variable, which can be connected to both plants and fish.

2. See: **Worksheet (Group) – Climate Change: Effects on Lake Michigan**

Wrap-up:

- What else can happen to Lake Michigan? Use the ‘Background’ section to talk about a few other points. Explaining how many beaches would have to close because of sewage overflow would be a good example, since most students would know about the numerous beach closures every year because of bacteria in the water. A list of variables to be used in other CLDs or connection circles is given below.

- Discuss the "Climate Change: Wrap-up"

Variables:

Water temperature increase →

Evaporation

Ice cover

Water levels

Suitable habitat for invasives (Asian carp, zebra mussels, round gobies)

Lake effect snow

Fish eggs

Lower year-class strength

Turnover and duration of stratification

Oxygen and nutrient supplies

Productivity

Food availability

Intense storms →

Runoff (urban and agriculture)

Beach closings

Costs

Sewage outflows

Algal growth (hosting bacteria)

Organism mortality

Soil erosion

Delivery of pollutants (nitrates, phosphates, pesticides

Teacher preparation:

- Clear the classroom so there is a large space to do the activity, or choose a favorable outdoor location
- Prepare the objects that the children will use for the role-playing (Oxygen, fish, CO2, plant, water temperature, ice cover, intense storms, water pollution). Use examples from Lake Michigan:
    - Fish: Smallmouth bass, rainbow trout, walleye, yellow perch, alewife
    - Plants (phytoplankton): blue-green algae, green algae, diatoms, flagellates

Resources:

The Waters Foundation 'Global Warming CLDs' - http://www.watersfoundation.org/index.cfm?fuseaction=content.display&id=164

The Creative Learning Exchange 'Keystone Species in an Ecosystem Using Connection Circles to Tell the Story' - http://clexchange.org/ftp/documents/x-curricular/CC2008-02ShapeKeystoneConxn.pdf

The Systems Thinking Playbook by Linda Booth Sweeney and Dennis Meadows

Healing Out Waters® - Great Lakes Coalition – 'Great Lakes Restoration & the Threat of Global Warming'

US EPA 'Climate Change Kids Site' - http://www.epa.gov/climatechange/kids/

Wisconsin DNR 'Global Warming is Hot Stuff!' - http://dnr.wi.gov/org/caer/ce/eek/earth/air/global.htm

OneWorld.net 'Hot Earth' - http://tiki.oneworld.net/global_warming/climate_home.html

ClimateChangeEducation.org 'GlobalWarmingKids.net' - http://globalwarmingkids.net/

Worksheet (Group) – Climate Change: Effects on Lake Michigan

1. How do you think a lower water level will affect the healthy Lake Michigan ecosystem?

2. What other effects do you think climate change may have on Lake Michigan?

3. What happened to the healthy Lake Michigan ecosystem when water temperature increased?

4. Explain one effect of climate change that threatens the ecosystem of Lake Michigan.

<u>Climate Change: Wrap-up</u>

Some of the students may feel a bit upset after learning about climate change. It is important to emphasize that THEY can DO things to help! Encourage them to do the things in the "How you can help section" below, both at home and in the classroom. Encourage them to tell their parents, family, and friends what they have learned. Maybe have classroom helpers each week whose jobs are to turn off the lights and the computers, and make sure that the proper materials are being recycled. Have books in the classroom that teach the students more about climate change and how to be environmentally friendly. The options of fun and educational things to do are endless!

How you can help:

- Don't leave lights on or turn them on if you don't need them
- If your destination is close, walk, bike, or roller blade instead of taking a car
- Take public transportation
- Turn off your computer and TV when you are not using them
- Unplug appliances when not in use
- Carpool to school or sports practices and games
- Reduce, reuse, and recycle
- Read to learn about the environment
- Talk to your friends and family about what you've learned

More to do with climate change locally:

"Climate Change," a temporary exhibit at the Field Museum in Chicago, is running from June 25, 2010 – November 28, 2010.

Children's books on climate change:

<u>The Down-to-Earth Guide to Global Warming</u> by Laurie David

<u>Our Choices: How We Can Solve the Climate Crisis</u> by Al Gore

A Hot Planet Needs Cool Kids: Understanding Climate Change and What You Can Do About It by Julie Hall and Sarah Lane

Why Are the Ice Caps Melting? By Anne Rockwell

Polar Bear, Why Is Your World Melting? By Robert E. Wells

A good movie to watch:

Disney's Wall-E

APENNDIX 4

The Fourth Learning Module: Asian Carp

A forth lesson plan on Asian carp was created, but only partially implemented due to time constraints. A few days before the day of implementation, it was decided that I should only implement the climate change lessons. This way, I would be able to focus my efforts on improving the lesson plans on climate change and spend more time during the program with each of the three lessons.

After I had finished delivering the climate change lessons to the students, we did play the Asian carp game. This was decided because there was a little time left over, and the game involves running around – something these kids love! Plus, I had worked hard on getting that lesson together. I asked the students before they played if they had any idea what an Asian carp was. Most knew that Asian carp is a fish, and assumed that it came from Asia. After a quick lecture on the species and a few rounds of the tag-game, the students were able to tell me that Asian carp invading Lake Michigan would be bad because the Asian carp would eat everything.

I did not include this lesson in the main portion of this thesis because it was not properly delivered nor assessed. Their attention was already lost during the third climate change lesson. Furthermore, since there is no direction connection between the two subjects, the students would have had to successfully shift their concentration away from climate change and onto another subject. Properly learning about Asian carp is not something that can be accomplished in 15 minutes. Although the students were able to understand that Asian carp would be a 'bad' thing for Lake Michigan because they eat a lot, the students were not able to give important details. I attribute this to the rush in the lecture, fatigued minds, and hungry stomachs. However, the Asian carp tag game was the students' favorite activity of the day! The game got the students running around, falling, laughing, and sweating. They kept asking to play another round, even though the pizza for lunch had already arrived. The minute they finished eating lunch, the students went back outside to play "Sharks and Minnows," the well-known game that the Asian carp game was modeled after, until their parents arrived. The folders for each student was made before the decision to focus on climate change, so the students still received all of the information on both subjects.

Any thorough, well-rounded lesson on the Lake Michigan ecosystem should include Asian carp. Although climate change is on a much larger scale, with a wider variety of negative effects, Asian carp is currently the most immediate threat to the Lake. Asian carp is a much more tangible subject; concepts are not as abstract, feedbacks not as numerous. By the fourth grade, students do understand food webs. They are familiar with terms such as: predator, prey, consumer, carnivore, etc. These students were even familiar with the subject of invasive species. They were able to define invasive species and give zebra mussels as an example of an invasive species in Lake Michigan. The students knew various ways in which invasive species entered Lake Michigan. Since they already had strong knowledge on the background information on the subject, it would have been interesting to see the deeper connections that the students may have been able to make if the lesson was given proper time and attention.

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