Understanding of Matter Transformation in Physical and Chemical Changes: Ecological Thinking

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Abstract

The focus of this study is how high school students can connect the idea of the conservation of matter in physical and chemical changes to the matter transformation processes in coupled human and natural environmental systems. Understanding environmental processes requires accounting for the flow of matter in and between systems and using appropriate model-based explanations to describe macroscopic processes in terms of atomic-molecular models. Connecting accounts of macroscopic matter transformations in and between systems to atomic-molecular explanations is fundamental to a scientific understanding of environmental systems. Most students were unable to do this consistently, especially for transformations between gases and solid or liquid materials. Three characteristic properties that students attribute to solids or liquids but not always gases are as follows: a) mass: students tend to treat gas as nothing and therefore having little or no mass, b) chemical identity: students tend to refer to gas as air or oxygen no matter what the actual gas is or wherever it comes from, and c) matter-energy distinction: students tend to focus on the conditions or forms of energy such as heat or pressure and consider those conditions as a reactants or products of matter transformations.

Key words: environmental science literacy, model-based reasoning, understanding of matter, matter transformation, environmental systems, conservation of matter, physical and chemical changes

Introduction

This paper is written as a part of larger research study focusing on environmental literacy. The focus of this study is presenting data from a study of high school students' understanding of matter transformations in physical and chemical changes in coupled human and natural systems connected with environmental literacy—the capacity to understand and participate in evidence-based discussions of the effects of human actions on environmental systems. In science education, understanding of the complex relationship between coupled human and natural systems, coupled biochemical and physical systems, and technology is important as the global ecological footprint continues to expand (AC-ERE, 2003; Wackernagle & Rees, 1996).

These phenomena are currently addressed in many state and national standards documents and in school curricula, but typically they are addressed in disconnected ways and we argue that they can fit together as a coherent conceptual domain that environmental citizenship stipulates. This paper is an examination of the high school chemistry students' scientific understanding of the concepts fundamental to these issues for a research-based learning progression for matter transformations in human and natural systems in both micro and macro levels fundamental to environmental literacy.

Research questions

- What is high school chemistry students' understanding about physical and chemical changes in terms of atomic molecular theory?
- How do they connect matter transformations in physical and chemical changes to the processes in natural environmental systems?

Significance of the study

Traditionally environmental education and science education have been separated from each other in the formal school curriculum. Little attention has been given to issues of environmental literacy in traditional science education research, nor the necessity of incorporating environmental literacy into scientific literacy in the formal science curriculum. For over the last two decades, a number of conceptual change studies reported how students' knowledge reconstruction occurs to accommodate their naïve theories to scientific knowledge in their conceptual ecologies. However, the context of the knowledge domain they examined remained in the realm of natural systems. No matter how researchers emphasized the acknowledgement of students' everyday experience, the experience needed to be translated into the account of pure physical science phenomena independently from the integrity of environmental systems. Also, sociocultural and critical science education research reported how students learn and think about physical phenomena in natural system under the influence of sociocultural and socioeconomic status differences. However, all these studies did not necessarily investigate students' ideas about scientific phenomena in the context of complex environmental system in local, regional or global levels.

Most importantly, contemporary cross-disciplinary concern about our ecological footprints and national standards' view of scientific enterprise as component of comprehensive and reliable understanding of the human species and its environment (AAAS, 1989) explicitly address the necessity of the integrity of scientific literacy and environmental literacy. We report the students' data about their understanding of matter transformations in physical and chemical changes in coupled human and natural systems. This study is limited that we didn't seek data about students' understanding of matter transformations in the larger scale - regional and global levels.

Background

This paper reports results from a long-term program of research whose goal is to increase the salience of environmental literacy in the required K-12 science curriculum. The program of research builds on developments in combining environmental education to current K-12 science curriculum and in learning progressions as a strategy for synthesizing research on science learning. Understanding environmental processes requires accounting for the flow of matter in and between coupled human and natural systems and using appropriate model-based explanations to describe macroscopic processes in terms of atomic-molecular models (Anderson et al., 2005; McComas 2003; Barker & Slingsby, 1998). Connecting accounts of macroscopic matter transformations in and between systems to atomic-molecular explanations is fundamental to a scientific understanding of environmental systems. However, researches have shown that most students were unable to do this consistently, especially for transformations between gases and solid or liquid materials (Gometz, Pozo, & Sanz, 1995; Driver, Squires, Rushworth, & Wood-Robinson, 1994; Hesse & Anderson, 1992; Bar & Travis, 1991; Stavy, 1990; Carey, 1985; Novick & Nussbaum, 1981).

To assist the reader, some of the key concepts, especially those of environmental education component are introduced in this section. Using Berkowitz's (in press) environmental citizenship and a new framework for ecological literacy definitions as a guiding frame, we used terms such as environmental literacy and ecological thinking.

Berkowitz's integrated framework for environmental citizenship includes five elements.

> *Ecological literacy.* Understanding the key ecological systems using sound ecological thinking, while understanding the nature of ecological science and its interface with society
>
> *Civics literacy.* Understanding the key social, economic, cultural, political systems using the requisite critical thinking skills

> *Values awareness.* Awareness of personal values with respect to the environment, and the ability to connect these values with knowledge and practical wisdom in order to make decisions and act
>
> *Self-efficacy.* Having the capacity to learn and act with respect to personal values and interests in the environment
>
> *Practical wisdom.* Possessing practical wisdom and skills for decision-making and acting with respect to the environment

Recognizing these critical components of environmental citizenship, we define environmental literacy as the capacity to understand and participate in evidence-based discussions of the effects of human actions on environmental systems or ecological systems. This paper will use the term environmental systems instead of ecological systems for the purpose of consistency. The environmental systems or ecological systems include human system as well as natural system. This is a guiding concept to defining ecological thinking in our vision.

Among Berkowitz's three dimensions of ecological literacy in a new framework, ecological thinking involves scientific, systems, trans-disciplinary, spatial, temporal, quantitative, and finally creative/empathic thinking. Because his definition of ecological thinking almost thoroughly includes all crucial components of thinking skills in ecological science and environmental education, we will adopt his definition of ecological thinking in a new framework to this paper.

<u>Integrating environmental literacy to science education</u>

The necessity of incorporating environmental literacy issues to formal science education is acknowledged by both communities and becomes a societal demand as our scientific enterprise and technology along with ecological footprint index has significant impact on human life. This can be viewed from science education, interdisciplinary, and ecological science approaches.

Science education approach

As *The Benchmarks for Science Literacy* (AAAS, 1993) indicates, the scientific enterprise is a main feature of the contemporary world. Along with scientific world view and scientific inquiry, it composes "comprehensive and reliable understanding of the human species and its environment (AAAS, 1989)." Also *Science for All Americans* (AAAS, 1989) speaks directly many of the concepts students need to understand ecosystems. "Flow of matter and energy" in Chapter 5 addresses these important ideas directly
(http://www.project2061.org/publications/sfaa/online/chap5.htm.)

> However complex the workings of living organisms, they share with all other natural systems the same physical principles of the conservation and transformation of matter and energy. Over long spans of time, matter and

> energy are transformed among living things, and between them and the physical environment. In these grand-scale cycles, the total amount of matter and energy remains constant, even though their form and location undergo continual change.

However, numerous studies about how students make sense of scientific phenomena indicate that a big gap still exists between students' understanding and scientific explanations of natural phenomena. In this case the ecological thinking involving the processes of matter transformations in and between systems which composes the fundamental ground of environmental literacy is hard to accomplish. As Blank & Brewer (2003), Bybee (2003), Anderson (2003), and Brewer (2002) argued we need to establish robust research-based teaching models for overcoming students' disconnection between microscopic and macroscopic explanations of physical phenomena and connecting scientific argument to environmental issues.

Trans-disciplinary and multidisciplinary approach

Also, in natural sciences, there are increased interdisciplinary studies about the interaction between human and natural systems and the researches emphasize the importance of the sustainability of the systems for the future living systems (Anderson et al, 2005; Berkowitz, Nilon, & Hollweg, 1999). It is therefore important for students to understand how scientific activities are organized in human society and there is increasing demand for K-12 science curriculum to incorporate these concerns because they are the commanders of the natural resources in the future and they need to know how to not exploit the bounty of the nature. However, a number of research studies have shown that students have difficulties in understanding the underlying principles and connecting macroscopic observations to microscopic explanations, which has pivotal importance to understand natural and human systems scientifically. Therefore we need to find a way to connect K-12 science education to environmental education in its conceptual sequences.

Also, environmental education recognizes the importance of viewing the environment within the context of human influences, incorporating an examination of economics, culture, political structure, and social equity as well as natural processes and systems (NAAEE, 1999; Bybee 2003). Characteristics of a new ecology education include trans-disciplinary and multidisciplinary approaches. Recognition of the inherent complexities and nonlinear properties of most environmental systems, larger temporal and spatial physical scales, human components such as economics and politics, and technology as an essential aspect of research and the means to address challenges for science education.

Ecological science approach

For connecting ecological thinking and environmental education in science classroom, Berkowitz (1999) suggests possible pathways and McComas (2003a, 2003b) envisioned how it can be linked to the formal K-12 science education.

Through biology textbook review, McComas diagnoses current effort of integrating ecological education components and provide recommendations for better environmental citizenship. He suggests ecology elements should be included within the context of a traditional year-long biology course which is woven throughout the complete K-12 school experience. McComas recommends two important perspectives for K-12 ecology curriculum. First, he refers to the *NAAEE (the North American Association for Environmental Education) Guidelines for Excellence in Environmental Education* (K-12)'s action-taking goals as the vital element of ecology curriculum. He states the reason as "strong decision making strategies and role-playing activities should be included to provide guidance and experience in making environmental decisions." McComas warns us that taking actions without understanding the science behind them is detrimental.

Therefore, the second important recommendation is that the ideal ecology curriculum should be guided by the application of authentic inquiry through laboratory investigations guided by NSES (1996) for attaining proper content. Finn, Maxwell, & Calver (2002) provide five principles of teaching ecology in secondary biology courses, focusing on integrating experimental ecology into the biology curriculum. They also emphasize that the degree to which students participate in the design and conduct of ecological experiments is an important component of an inquiry based approach to the teaching of ecology. Their conclusion is that despite the constraints of curricular requirements, time, finances and logistics, the teaching of ecology can be enriched by explicit consideration of manipulative experiments. Moreover, ecological knowledge and the inquiry-based approach in that experimental ecology are too valuable to the development of scientific literacy to be compartmentalized in curricula.

Brewer argues (2002) authentic experiences of collaborative ecological investigation in schoolyard laboratories among teachers, students and conservation biologists enhance scientific understanding of the world and have a positive influence on the future environmental attitudes. Brewer gives an example how teachers can have the ecological lens after working with ecologists and learn how to utilize schoolyard as an instructional resource. To do so, teachers wanted to know the names and general natural-history traits of common organisms in their schoolyards.

Also research from the viewpoint of cultural inclusion (Lee & Luykx, 2003) argues that ecology education provides a context for the construction of scientific knowledge in which non-mainstream student may participate on a more equal footing. Students' cultural and linguistic knowledge related to the ecologies of their home communities can provide rich opportunities to share and develop collective reasoning and understanding of ecological issues from multicultural and global perspectives.

Students' ideas of physical and chemical changes

The principle of mass and energy conservation governs the contents of basic natural science studies such as physics and chemistry. The concept of physical change require many prerequisite knowledge of different physical and chemical properties such as molecular structure, intermolecular forces and bonding, molecular motion of the same chemical substance but in different phases of solid, liquid, and gas. Also, the knowledge of thermodynamics of the change of state as well as the conservation of mass and energy is necessary. Understanding of chemical change requires atomic level understanding of those described above and it involves more complex concepts both in qualitative understanding and quantitative representation of the understanding. Chemical change refers fundamentally the change of the identity of matter, therefore atomic rearrangement by bond-breaking and bond-forming and accompanied energy transformation always necessarily occurs. In addition, students need to understand what chemical formula and chemical reaction equations mean in terms of all kinds of changes explained above in both atomic and molecular level. NSES expresses this idea of requirement for high school physical science students as follows in the content standard:

> High-school students develop the ability to relate the macroscopic properties of substances that they study in grades K-8 to the microscopic structure of substances. This development in understanding requires students to move among three domains of thought--the macroscopic world of observable phenomena, the microscopic world of molecules, atoms, and subatomic particles, and the symbolic and mathematical world of chemical formulas, equations, and symbols.

Studies about students' ideas of physical and chemical changes focused on either the conservation of the quantity (mass, weight, volume, etc.) or the conservation of quality (chemical identity, atomic mass, etc.) without strict differentiation of the boundaries of those two. There are two major reasons: one, because students revealed great confusion between physical and chemical changes and most of the studies' analyses depended upon students' responses which encompassed different conceptual dimensions fragmented and inconsistent. Two, the participants in most of the studies were young children. Studies that targeted high school students also used similar instruments mainly in order to investigate the relation between cognitive development and the conceptual acquisition and finally appropriate educational sequence of teaching science concepts.

For example, Gomez Crespo, Pozo, & Sanz (1995) studied 12- to 17-year-olds and college students' ideas on conservation of matter in physical and chemical changes and stated that 'when matter undergoes a physical change, the substances do not change their microscopic structure, and thus they conserve their identity. The chemical structure of water remains unchanged when it is transformed into ice. Alternatively in chemical changes the identity of the substances involved is modified by the interaction between the molecules of the initial substances that generates new substances. Thus, after a chemical reaction initial substances are not conserved. What takes place is reorganization of microscopic structure of matter, so that the atoms are conserved, but with a different organization and distribution.'

Even if subjects of this study are older than most of the other studies, the concepts employed to explain the target concepts that they like to investigate is broadly defined. They mentioned, 'chemical structure of water remains unchanged when it is transformed into ice' and explained it as no change in microscopic structure in physical change. The intramolecular structure of water is not changed but its intermolecular structure and forces are completely changed when it is transformed into ice. Just saying microscopic level does not explain the differences between molecular and atomic level structure, motion, bond, and energy. The fact is that NSES content standards require this differentiation in high school level and is taught and assessed in high school chemistry classes.

Gomez Crespo et al.'s argument is that most of the studies done on chemistry learning aimed particulate nature of matter and mostly focused on the conservation of quantities such as mass or weight or number and sizes of particles (Stavy, 1990; Gable, Samuel, & Hunn, 1987; Novick & Nussbaum, 1981, 1985). They investigated students' ideas of conservation of properties, that is, conservation of substance in physical and chemical changes without differentiating atomic level and molecular level conservation of properties. The result of Pozo & Gometz Crespo (2005)'s study confirmed that consistent use of this kind of intuitive representations, as against scientific ones, constitute implicit theories that is strongly rooted in diverse knowledge domains and difficult to modify through conceptual change instruction (Gopnik & Meltzoff, 1997; Carey, 1995; Vosniadou, 1994). They further argued the embodied nature of the implicit theories in terms of its consistency.

A common obstacle in science learning detected from almost all alternative conceptions research is the difficulty in transferring scientific knowledge, acquired in an academic context to experiential everyday situation (Pines & West, 1985). Hesse & Anderson (1992) found majority of high school students preferred explanations of chemical change based on superficial analogies with everyday events over explanations based on chemical theories. Basically students in their study failed to invoke atoms and molecules as explanatory constructs and also in 'conservation reasoning' the subjects couldn't explain the mass conservation in chemical changes and had problems in understanding the role of invisible/unobservable gaseous substances in chemical changes even after explicit chemistry lessons.

Stavy's (1990) study about students' conceptions of changes of the state from liquid to gas also revealed the idea that gas has no weight, or that gas is lighter than the same material in its liquid or solid state. Studies reported similar results that students have great difficulty understanding properties of invisible substances and explaining physical and chemical changes in terms of atomic-molecular theory (Smith, Wiser, Anderson, & Krajcik, ; Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, 1993). Lee et al. (1993) identified students' difficulties in understanding molecular conceptions concerning the nature, arrangement, and motion of molecules as well as macroscopic conceptions of matter and physical changes of matter.

Stavy (1990) also found that recognition of the conservation of mass in one task does not necessarily transfer to other tasks. Similar results were obtained from many other studies (Smith, Maclin, Grosslight, & Davis, 1997; Carey, 1985; Driver, Guesne, & Tiberghien, 1985). Carey (1985) explained domain specific knowledge as 'theory changes, and novice-expert shift as well, involve restructuring, but only of the concepts and explanatory principles of the domains of knowledge undergoing development' after extensive research of knowledge reorganization in childhood in 1970s for extensive content areas. Driver et al. (1985)'s work supports this claim with English counterparts' data and the correspondent scale of study in terms of the content coverage and the theoretical synthesis of the data.

In spite of over 12 years of formal science education, high school students have great difficulties in understanding the nature and structure of atoms, molecules, kinetic molecular theory and so does in understanding conservation of mass and energy. These are all crucial to understanding the principle and processes of matter transformations in and between human and natural systems. Moreover, understanding these concepts in ecological processes demands students to expand their accounts to additional temporal and spatial dimensions of thinking.

<u>Students' ideas of matter transformations in environmental systems</u>

The idea of matter transformation and the plant as the basis of the survival of all living things establishes fundamental links for understanding interdependency and matter cycling regarding to the conservation of mass within and between environmental systems. Conceptual change research on phenomena associated with the processes of matter transformation in environmental system focuses on photosynthesis, respiration, nutrition, food web, growth, and decay. Students' conceptions of living things and nonliving things are excluded from the discussion in this study because it does not directly affect tracing matter. The integrity of ecological thinking about matter transformations in environmental system requires the recognition of the cause and consequences of the processes and conditions of matter cycling in environmental systems as well as the scientific knowledge of matter and its change in molecular and atomic level.

The relationship of photosynthesis and respiration is difficult for students to understand not only in macroscopic narrative explanation of phenomena but also in microscopic understanding of molecular transformations. Anderson, Sheldon, & DuBay (1990) claimed the importance of this concept as a 'prerequisite for any systematic understanding of ecology. Food chains and food webs begin with photosynthesis and end in respiration. Photosynthesis and respiration are the essential processes in the most matter cycle…photosynthesis and respiration play essential roles in the flow of energy through ecosystems.' Their study showed most of students held definitions of respiration, photosynthesis, and food in its 'common-language sense' not in 'biological' – scientific- terms. What made it worse is this confusion is not merely word usage problem but it turned out to be 'the symptoms of basic misconception about how plants and animals use matter and energy.'

Matter transformation of gaseous substances is the most problematic issue for students. They tend not to attribute weight increase and growth to the incorporation of gaseous molecules (Stavy, Eisen, & Yaakobi, 1987). A common finding about students' reasoning about transformation of gaseous substances is that students fail to trace the matter and therefore cannot conserve the mass (Anderson et al., 1990). Carey (1985) and Leach, Driver, Scott, & Wood-Robinson (1996) also reported that students held teleological ideas about ecological processes – plants make food for the benefit of animals and people. Students' accounts of matter flow in environmental system seem to be based on isolated, linear, fragmented explanation rather than integrative, interdependent systems thinking. Driver et al. (1994) cited Smith & Anderson (1986) that 12-year old subjects are mostly aware of some kind of cyclic process in ecosystems but most students thought in terms of sequences of cause and effect events, with matter being created or destroyed, and then sequence starting again. Students' conceptions of matter cycling processes remained fragmented even after instruction; only 4% of students understood that matter is converted back and forth between organisms' bodies and substances (carbon dioxide, water and minerals) in the environment.

The result of Bell's (1985) study showed that students have much better understanding of what happened to oxygen than to carbon dioxide in photosynthesis and respiration even though oxygen was often equated with air. Students very rarely traced carbon dioxide as the source material of food for a bean plant or a person in Anderson et al.'s (1990) study. Less than a third of 16-year old students noted carbon dioxide and oxygen as the source material for life of organisms in Leach et al. (1996)'s study.

This study is the report of the data about high school chemistry students' environmental literacy regarding physical and chemical changes, including students' accounts of matter transformation in physical science perspective and students' ecological thinking about matter transformation in environmental systems. We investigated students' accounts of changes in sublimation, boiling, burning, and oxidation contexts. Matter transformation in environmental systems is examined in fat loss and inter-systemic conservation of mass context. Our goal is to know how student link a) invisible atomic molecular explanation of physical and chemical changes in material systems, b) observable vitalistic ideas of changes in living systems, and c) conservation of mass through matter cycling in a sequence of events occurring between systems. This integrity and interdependency is the vital element to understand environmental systems as coupled human and natural systems.

Methods

The present exploratory study assessed high school chemistry students' atomic-molecular level and macroscopic level understanding of matter transformation in coupled human and natural systems. In this section we describe (a) a way of viewing environmental systems as matter transforming system (b) data sources - the test and the subjects-, and (c) data analysis procedure guided by *analytic induction* (Goets & LeCompte, 1984) which governs the overall process of extraction and construction of the core theme of the study and *phenomenological interpretation* method (Marton, 1981; Marton & Booth, 1997) in qualifying the content of the analysis.

In our analysis we (a) investigated the range and character of students' responses to our specific questions about matter transformations in physical and chemical changes, (b) interpreted the concept relations in students' ecological thinking in terms of their understanding of scientific principles of environmental systems, (c) created phenomenological categories for students' concept relations, and (d) constructed core issues in students' ecological thinking about matter transformations in environmental systems.

Environmental literacy is a complex accomplishment, requiring mastery of many ideas that are related, but currently taught separately in the science curriculum. Environmental systems are matter-transforming systems, and many environmental issues (e.g., global warming, pollution, ozone depletion) hinge on human actions and technologies that lead to accumulation or shortages of particular kinds of matter. Thus students need to understand how matter is transformed in physical and chemical changes in terms of macroscopic understandings of materials and substances as well as microscopic understandings of atoms and molecules. Therefore we developed a test called *Physical & Chemical Change Test* for middle and high school students and included answer keys for teachers' reference as shown in Appendix A.

Data sources

The primary data source is the test administered in four 10th grade science classrooms. 40 students are from a suburban high school 10th grade and 40 students are from an International Baccalaureate Program 10th grade. Students' group from both schools is a mixed population of general and AP chemistry courses. The purpose of the study is to learn about high school students' account of scientific phenomena in coupled human and natural physical systems, not a comparison of different groups of students. Therefore, we report data as an integrated one throughout this paper.

Initial drafts of the tests were based on reviews of existing research. We developed a test that combined items from previous research with new items focusing on application of key ideas in the topic to coupled human and natural systems. This study used 12 written questionnaires composed of 4 multiple choice, 1 true-false, and 6 written statements and 2 of the written statements are parts of 2-tiered questionnaires with associated multiple choice questions. The source materials we used to develop the questionnaires are from a) "Conceptual Questions(CQs): Chemical Concepts Inventory" (http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/CQs/ConceptsInventory/Concepts_Inventory.html) for questions 1, 2, 3, 4, 5, 6, 7, and 8, and "Draft: Implications of Research in Children's Learning for Assessment (Anderson, 2003, http://scires.educ.msu.edu/Science05/Assets/802Files/Andy/Draft%20Report%20for%20Distributi.doc) for questions 9 and 10. Finally, questions 11 and 12 are developed by the authors.

The rubrics for each question are developed for coding students' responses and are designed to highlight aspects of the students' responses relevant to the general theme of environmental literacy (Appendix B).

Teachers participating in the working groups in Environmental Literacy Project (Principal Investigator: Charles W. Anderson) administered the tests to their students. The test was revised based on the results of the initial test. The summary in this paper is based on the original draft of the test.

The test

The following table 1. shows the combination of the types of test items, their target concept of measurement in changes, and the context of the question.

Table 1. Measuring target of test items

Item	Type	Measured concept		Context	
		Physical change	Chemical change	Natural system	Human system
1. iodine in the tube	Two-tiered (multiple choice)	• Sublimation • Conservation of mass within system		V	
2. iodine in the tube	Two-tiered (written explanation)	• Sublimation		V	
3. boiling water	Open-ended	• Boiling • Change of phase • Intermolecular forces and motion in phase change		V	
4. SO_3 formation	Multiple-choice		• Atomic –molecular representation in chemical reaction	V	
5. wood burning	Two-tiered (true-false)		• Burning • Matter transformation between systems	V	
6. wood burning	Two-tiered (written explanation)		• Burning	V	
7. iron rust	Multiple-choice		• Rusting • Matter transformation between systems	V	
8. water vapor	Multiple-choice	• Boiling • Kinetic molecular theory of gas • Intermolecular forces and motion in liquid and gas		v	
9. ice	Two-tiered (multiple choice)	• Molecular crystalline structure		v	
10. ice	Two-tiered (written explanation)	• Intermolecular bonding and motion in solid and liquid		v	
11. weight loss	Open-ended		• Fat loss in human body • Matter transformation in and between systems	v	V
12. gain or loss	Open-ended	• Conservation of mass in physical change and in matter transformations in and between systems	• Conservation of mass in chemical change and in matter transformations in and between systems	v	V

Data Analysis Procedure

The overall procedure of the data analysis was done according to a phenomenological process that elicited the relations of concepts expressed in students' responses. First, we developed rubrics for scoring students' responses for each questions a a primary data analysis. The principle of developing rubrics was differentiating students' ideas, looking for evidence of scientific model-based reasoning or of narrative reasoning which involves partial understanding with alternative explanations. The general scheme of the categorization of students' responses are; scientific-model based reasoning, several partial narrative understandings differentiated by the categories of concepts students employ in their explanations, and unintelligible understanding which shows fragmented piecemeal of explanations, and finally no response. The number of categories differs from question to questions. All these procedures are shown in Appendix B.

In the second stage of our analysis we identified relations among concepts analysis. Third, we interpreted concept relations and created phenomenographic categories. Finally we were able to do construct the core themes in students' conceptual relations encompassing the categories particularly important to understanding matter transformations in physical and chemical changes for environmental literacy.

<u>Development of coding systems for identification of relations of concepts</u>

First stage of the data analysis is guided by Working Paper with rubrics (Appendix B) for coding students' responses. Each rubric classifies students' response in a hierarchical manner from scientific model-based reasoning to narrative reasoning and to unintelligible or no response. Anderson (2003) explains scientific knowledge and practice as Observations-Patterns-Models framework in which scientific inquiry is understood as scientific reasoning process from evidences in Observations and scientific application is understood as scientific reasoning from Models and Patterns. Scientific practice as inquiry and application is the scientific reasoning processes and it deliberately utilizes scientific knowledge of Observations, Patterns, and Models, from the individual facts to the scientific theories.

The rubrics were designed to highlight aspects of the students' responses relevant to the general theme of environmental literacy and the specific trends in the succession of students' reasoning. Reliability of the rubrics was assessed by having a second coder independently code a sample of the tests. When there are discrepancies, the rubrics are revised. For most of the rubrics, two or more rounds of revision were needed before satisfactory reliability was achieved. Additional revisions are based on discussions among the Working Group leaders in the Environmental Literacy project, as we developed our ideas about connecting ideas and themes as a whole group.

Table 2 shows the summary of students' responses for each item. The summary includes the numbers and ratios of students' response from scientific to narrative understandings. The hierarchical range of differentiation between scientific and narrative understandings is shown in the rubrics in Appendix B.

Interpreting relations among concepts and creating phenomenographic categories

Once the relations of concepts were identified, the next task was to interpret them in order to create phenomenographic categories. When creating categories of student conceptions, one needs to follow a specific set of criteria. According to Marton and Booth (1997), the following criteria for creating categories must be met.

a) Individually, categories should each stand in clear relation to phenomenon of the investigation, so that each one tells us something distinct about a way of experiencing that phenomenon.
b) Categories must be hierarchical, that is, they must progress from simple to complex relations.
c) The system of categorization should be parsimonious, that is, as few categories as is feasibly and reasonably possible should be explicated.

Two research questions can be addressed by phenomenography: (a) how do students' conceptions of a natural phenomenon or scientific concept generally vary? How can the regularities among variations be represented? (b) How can a specific student be compared with other students in terms of his/her conceptions of a natural phenomenon or scientific concept? In phenomenography, the second-order question described above in (a) can be answered by developing categories of students' conceptions, and the first-order question described above in (b) is answered by comparing a student's conception to the categories developed. Marton (1981) metaphorically describes these categories as occupying a type of outcome space where a given individual can somewhat freely employ varying conceptions, depending upon the contextual features for a particular problem setting.

The focus of this study is to understanding students' ecological thinking of matter transformation in physical and chemical changes within/between environmental systems. The hierarchical structure of students' ecological thinking is reflected in the rubric from scientific-model-based reasoning to narrative reasoning about each phenomenon. We focused on creating parsimonious categories that best reflect students' understanding on issues intended and represented by each item of the test.

Constructing and clustering core themes in the relations among concepts

From first analysis of individual question and response level to identification of categories of description, and from the relation between the categories within which we searched for insight, we tried to find out the most critical aspect of the questions we are asking through this study. We present most characteristic findings about students' account of matter transformation in environmental system encompassing both molecular-atomic physical science dimension and coupled human and natural systems by this process. The focus is to what are the hindrance of students' account of matter flow and conservation of mass in environmental systems in terms of scientific explanatory capability about behind principles.

Conceptual Framework

The conceptual framework of this study is comprised of two dimensions. They are derived from two studies of scientific model-based reasoning about environmental systems (Anderson, 2005) and ecological thinking skills (Berkowitz, 2003).

Environmental literacy

Anderson gives an explanation of the scientific model-based reasoning model of environmental literacy and the following is the four elements among total seven of them relevant to this study.

1. Model-based reasoning about processes in systems

Most students think that what they are learning in science class consists of facts—verified statements about the world. "Plants use light energy to make sugar from water and carbon dioxide" is also a fact in this sense, but it is also a model-based statement that can be used as a *conceptual tool* for reasoning about plants. Our challenge in promoting environmental literacy is to help students recognize the power of models and use them appropriately. Many students seem to make sense of the world in terms of *narratives about sequences of events,* rather than reasoning in model-based ways about processes in systems. For example, many students who can give describe steps in the process of photosynthesis (narrative) fail to invoke photosynthesis to explain how plants gain weight as they grow (model-based).

2. Tracing matter through systems

Environmental systems, including both their human and natural components, consist of pools of matter connected by processes that transform and/or transport matter. Students who can use this idea in a model-based way:

- Focus on tracing substances as a key aspect of understanding processes (i.e., tracing substances in addition to events-based narratives)
- Can reason about matter-transforming processes at both the macroscopic and the atomic-molecular level
- Uses key rules or constraints to reason about environmental matter transformation (e.g., conservation of mass, substances and molecules in physical changes, elements and atoms in chemical changes.
- Avoids key problems or misconceptions (e.g., matter-energy conversion, not assigning mass to gases)

3. Connecting accounts of molecular, cellular, organismal, and environmental processes

Processes in environmental systems work simultaneously at multiple scales, from the molecular level to the earth's biosphere. Students need to reason about how processes that occur at one scale affect, and are affected by, processes that occur at other scales.

4. Quantitative reasoning with data and models

Many scientific models depend on and use complex patterns in data. These data are collected and displayed in many ways: tables, graphs, formulas, maps, etc. Thus students need to relate models to data through statistical, geographical, or other means. To reason well with data and models, students need to:

- Extend their experiences, gaining personal, "experientially real" experience with environmental systems and collect qualitative and quantitative data about those systems.
- Find patterns in data and suggest explanations for those patterns.
- Appreciate the nature and limits of statistical techniques for finding patterns in data that are not completely certain.
- Appreciate the nature and limits of predictions based on statistical models (e.g., global climate models), critiquing both the assumptions of models and the quality of data.

Ecological thinking

We address four elements of ecological thinking skills adapted from among Berkowitz (2003)'s seven. Conceptualizing ecological thinking needs to go beyond the classical proposition that 'everything is connected' as posed by Orr (1993). We emphasize the notion that we are components within ecosystems and at the same time we cause negative or positive changes of ecosystems (AC-ERE, 2003; Wackernagle & Rees, 1996; McDonnell & Pickett, 1993). Berkowitz also argues that the following kinds of thinking are necessary to understand how people's actions shape ecosystems.

- *Scientific or evidence-based thinking* is required to understand and evaluate the different sources of evidence addressing ecological questions, and to investigate and participate in the collection and application of evidence to address questions they have about the environment.
- *Systems thinking* is necessary to define an object of study in the environmental system with all the key components and their connections specified and bounded in time and space.
- *Trans-disciplinary thinking* enables people to apply understandings of the environment from the other natural sciences such as physics, chemistry, geology, hydrology, meterology, mathematics and the social sciences to ecological phenomena.

- *Quantitative thinking* is to appreciate the nature and basic source of variability in ecological processes and controlling factors in coping with highly stochastic and variable nature of ecosystems.

Results

This section describes the process of constructing core themes in students' conceptual relations about matter transformation from both physical science and ecological thinking perspectives. We report students' responses for each test item and cluster them into the categories of concept relations based on phenomenological interpretations.

Students' responses

Total 80 high school students response for each question is listed in the table 2.

Table 2. Test result

Item	Students' response
1. iodine in the tube	42 of 80 (52.5 %) said less than 27g 38 of 80 (47.5 %) said 27g
2. iodine in the tube	14 of 80 (17.5%) said gas is lighter than solid. 4 of 80 (5%) said gas produced by heating solid is displaced by air and weighs less than air
3. boiling water	23 of 80 (28.75%) said water vapor 28 of 80 (35%) said hydrogen gas or oxygen gas or both 26 of 80 (32.5%) said air or air and other gas such as carbon dioxide 3 of 80 (3.75%) no response or unintelligible answer
4. SO_3 formation	Only 15 of 80 (18.75%) chose correct visual representation 38 of 80 (47.5%) confused coefficient of chemical reaction with number of atoms and also showed misunderstanding of stoichiometry 17 of 80 (21.25%) showed misunderstanding of stoichiometry 10 of 80 (12.5%) showed misunderstanding of molecular formula
5. wood burning	When a piece of wood burns, some matter is destroyed. True or false? 65 of 80 (81.25%) said False 15 of 80 (18.75%) said True
6. wood burning	Only 5 of 80 (6.23%) understood conservation of mass in molecular transformations with rearrangement of atoms Sample answer: No change of atomic structure, broken down but no matter is destroyed 53 of 80 (66.25%) understood burning as change of matter form such as matter changes to ash or smoke 6 of 80 (7.5%) understood burning as phase change Sample answer: because matter cannot be destroyed or created, it simply changes phase 3 of 8 (3.75%) said burning destroys matter and changed into gases Sample answer: something burn up into nothing or a type of gas 3 of 8 (3.75%) said burning destroys matter and changed into ashes Sample answer: turn into ashes 7 of 80 (8.75%) said burning destroys some or all matter Sample answer: Burning is destroying something Burnt and disappear into nothing
7. iron rust	41 of 80 (51.25%) said more than the nail it came from 17 of 80 (21.25%) said less than the nail it came from 14 of 80 (17.5%) said the same as the nail it came from 8 of 80 (10%) said it is impossible to predict

8. water vapor	27 of 80 (34.75 %) marked b) or d) which show the confusion of phase change with atomic rearrangement or molecular decomposition into atoms 12 of 80 (15 %) marked a) which shows confusion of phase change with hydrolysis or with decomposition reaction 6 of 80 (7.5 %) marked c) which shows disappearance of substance 34 of 80 (42.5 %) marked e), correct answer 1 of 80 (1.25%) no response
9. ice	30 of 80 (37.5%) said nothing 42 of 80 (52.5%) said air 4 of 80 (5%) said water 3 of 80 (3.75%) said ice 1 of 80 (1.25%) no response
10. ice	Only 8 of 80 (10%) said about microscopic structure and stronger bond energy 11 of 80(13.75%) said about macroscopic property of slow movement 5 of 80 (6.25%) said about macroscopic property of compact packing(condense) 24 of 80 (30%) said macroscopic property of distance (molecules are closer together) 28 0f 80 (35%) said simple macroscopic properties such as frozen molecules bunch together or more molecules are packed in
11. weight loss	Only 6 of 80 (7.5%) said no mass change in a total (systems thinking and mass conservation in a gaseous form as well as liquid and solid forms) 5 of 80 (6.25%) said fat mass leaves the body as solid or liquid forms 21 of 80 (26.25%) said fat mass is just gone (arithmetic subtraction) 28 0f 80 (35%) said fat is converted to energy or source of energy 10 of 80 (12.5%) said fat mass is converted protein or muscle
12. gain or loss	32 of 80 (40%) said no mass change unless something is taken away or added 15 of 80 (18.75%) said living things or non living things gain or lose weight by physical/chemical changes or natural growth/death - Water as a solid and liquid, it is heavy but as a gas, it is almost weightless 7 of 80 (8.75%) said when liquid is boiled, gas mixes with air and adds weight 14 of 80 (17.5%) said change of force of gravity can cause weight difference

Identifying relations of concepts

We identified students' explanations based on scientific model-based reasoning in the rubrics and table 2. This section is devoted to finding and explaining most frequent alternative conceptions and their naïve explanatory framework in order to identify the relations of concepts in students' narrative reasoning. Table 3. demonstrates students' conceptions and the relations of concepts in them.

Table 3. Identification of relations of concepts of matter transformation

	Students' conceptions	Identified relations of concepts
Iodine in the tube	Gas is lighter than solid when sublimation from solid to gas occurs (52.5%).	In physical change (sublimation from solid to gas) mass of solid is not conserved when it is changed into gas. State of matter is associated with change of mass – gas is lighter than solid. (52.5%)
	Physical change from solid to gas by heating produces air (5%)	The gas produced by sublimation of solid substituted with air. (5%)
	Gas weighs less than the air (>5%).	Gas weighs less than the air. (> 5%)
Boiling water	In physical change from liquid water to water vapor, hydrogen and oxygen gas are produced (35%).	Physical change is confused with chemical change in boiling of water. The change of the state of water from liquid to gas is considered as hydrolysis of water into hydrogen and oxygen gases. (35%)

	In physical change from liquid water to water vapor, air is produced (32.5%).	Boiling of water produces air. (32.5%).
SO_3 formation	In chemical reaction represented in particulate model, coefficient of chemical reaction which represents the number of molecules of reactant or products is confused with the number of atoms that constitutes molecules (68.75%) Disconnection between molecular formula and particulate representation of models of atoms and molecules (12.5%)	Particulate properties of atoms and molecules are confused. (68.75%) Disconnection between molecular formula and particulate representation of models of atoms and molecules (12.5%)
Wood burning	When it is burned, the matter form of wood changes into ashes and/or smoke (66.25%). Burning does not destroy or create matter but simply is a phase change (7.5%). Burning destroys matter or changes matter into gas (3.75%) Burning destroys matter and changes matter into ashes (3.75%) Burning destroys some matter or whole matter into nothing (8.75%)	Burning changes matter into ashes and smoke. (66.25%) Chemical change of burning is confused with physical change of change of phase (7.5%). –also mass conservation is mentioned as a memorized fact. Burning is understood as destroying something and change into gas, therefore the assumption is that burning leaves some gases and some matter is destroyed and the amount of mass is decreased. (3.75%) – no systems thinking Burning is understood as destroying something and change into ashes, therefore the assumption is that burning leaves some ashes and some matter is destroyed and the amount of mass is decreased. (3.75%)- no systems thinking Burning destroys matter into nothing (8.75%) – no systems thinking
Iron rust	Rust is something from iron itself and the added mass from oxygen in the air is disregarded (48.75%)	When a chemical reaction involves reactant from air such as in oxidation of iron in forming iron rust, added mass disregarded (48.75%)
Water vapor	Phase change from liquid water to water vapor is regarded as chemical change and molecular rearrangement (49.75%) When liquid water changes into water vapor it remains nothing (7.5%)	Physical change of boiling water is confused with chemical change of hydrolysis or water decomposition reaction. (49.75%) Boiling makes liquid water disappear into nothing. (In boiling, liquid water changes into nothing) (7.5%)
Ice	Air fills the empty space in ice crystalline structure (52.5%) Ice crystalline structure is filled with H_2O molecules either solid or liquid form (8.75%)	Air fills every empty space in atomic-molecular level not only between macroscopic substances in atmosphere. (Air fills the empty space in ice crystalline structure (52.5%) Solid structure is packed with molecules and has no empty space. (Ice crystalline structure is filled with H_2O molecules either solid or liquid form) (8.75%)
Weight loss	Fat mass leaves human system as solid or liquid forms of matter (6.25%) Arithmetic subtraction of fat mass from human body (26.25%) – simply fat mass is regarded as burnt up to nothing	Gas form of substances is often disregarded in chemical changes and mater transformations. (6.25%) – when gas is involved in changes, it is disregarded as if it doesn't exist. Matter transformation between human system and natural system is disregarded. Students fail to trace matter between systems and consider matter as disappearing. Burning destroys matter and converted into

		nothing. (26.25%)
	Fat mass is converted to energy or source of energy (35%)	Matter transformation by chemical change is confused with matter-energy transformation. Decomposition reaction of fat molecule is regarded as energy creating process. (35%)-inappropriate application of matter-energy transformation and failing systems thinking
	Fat mass is converted to protein or muscle (12.5%)	Teleological view of fat loss (12.5%)-no matter transfer between systems (failing systems thinking)
Gain or loss	Living things or non living things gain or lose weight by physical/chemical changes or natural growth/death- Water as a solid and liquid, it is heavy but as a gas, it is almost weightless (18.75%)	Matter transformations in physical and chemical changes cause changes of mass. Gas is lighter than its solid or liquid form. Gas is even considered as weightless. Matter transformations between systems in natural growth/death) are not properly understood. (18.75%)
	The gas produced by boiling in physical change process mixes with air and adds weight (8.75%)	Gas form of substances is often related to air as a mixture with air and often gases are considered as lighter than air regardless of the kind of gas. (8.75%)
	Change of force of gravity can cause weight difference (17.5%)	Weight and mass differentiation by specific gravity (17.5%) – scientific reasoning from physical science perspective

Narrative and Model-Based reasoning

Narrative and model-based reasoning is in some ways a “nature of science” variable in that it focuses on metacognitive or epistemological commitments that affect people’s understanding of science. Rather than focusing on issues from the history of science or questions about how adult scientists reason, however, this trend focuses on epistemological commitments that are implicit in people’s explanations and predictions about the world around them. Children and adults reveal in the form and content of their accounts how they think about the scientific enterprise and scientific reasoning.

We can contrast a model-based way of understanding phenomena as *processes in systems* with a narrative way of understanding as *events caused by actors in settings* (Anderson, 2003; Bruner, 1985; Olson, 2005). These two ways of understanding the world are complementary; a deep understanding of phenomena is both narrative and model based. Most people, though, find narrative ways of understanding easier, so the challenge that most science curricula face is helping students to recognize and use model-based reasoning (Lehrer & Schauble, in press; Stewart, Cartier, and Passmore, 2005).

In the following we answered for the questions: a) what percentage of students did show evidence of narrative reasoning?, b) what percentage of students did show evidence of incomplete model-based reasoning, in other words, what percentage of them didn’t answer correctly because of the ignorance of essential facts despite they were trying to reason in a model-based way?, and c) what percentage of the students did show evidence of model-based reasoning? Table 4. shows the summary of students' reasoning types for each question.

Table 4. Students' narrative and model-based reasoning types about physical and chemical changes

	Model-based reasoning	Incomplete model-based reasoning	Narrative Reasoning
Iodine in the tube	47.5% conserved mass in physical change	17.5% explained that gas is liter than solid because the density of gas is smaller than solid	35% said heat produced air, gas is lighter than air, gas is substituted by air etc.
Boiling water	28.75% conserved the identity of matter in physical change	35% explained physical change as an chemical decomposition reaction into hydrogen and oxygen gases	36.25% said boiling produced air or other gases or nothing
SO_3 formation	18.75% conserved atomic mass and represented atoms and molecules correctly in chemical rearrangement reaction	21.25% failed understand stoichiometry but conserved molecular identity 12.5% couldn't understand molecular formula but conserved atomic identity	47.5% didn't understand any chemical symbols and representations for atoms and molecules
Wood burning	6.23% conserved mass in molecular transformations with rearrangement of atoms	66.25% explained burning as change into other solid matter form 7.5% explained burning as change into gas form including air 7.5% explained burning as phase change	8.755 said burning is destroying
Iron rust	51.25% conserved mass and understood oxidation process	17.5% tried to conserve the mass but disregard the reactant from air	31.25% didn't understand the chemical change process and the matters involved
Water vapor	42.5% understood kinetic molecular theory of gas and mass conservation in phase change	34.75 % confused phase change with atomic rearrangement or molecular decomposition into atoms 15 % confused phase change with hydrolysis or with decomposition reaction	8.75% said disappearance of matter or no response
Ice	10% understood microscopic atomic structure in relation to bond energy	13.75% explained macroscopic property of slow movement 6.25% explained macroscopic property of compact packing (density) 30% explained macroscopic property of distance	35% said frozen molecules bunch together
Weight loss	7.5% conserved mass	6.25% conserved mass only in liquid or solid matter forms	26.25% just subtracted the fat mass 35% converted mass to energy 12.5% converted fat mass to muscle or protein
Gain or loss	40% conserved mass	18.75% explained living things or non living things gain or lose weight by	8.75% said when liquid is boiled, gas mixes with air and adds weight

	physical/chemical changes or natural growth/death 17.5% explained change of force of gravity can cause weight difference	

The following is the summary of the relations of concepts appeared in the students' narrative reasoning in Table 3. and Table 4.

- In the change of state mass often is not conserved when the change involves gas production. Also gas is associated with air either change into air or mixed with air regardless of the kind of gas in either open or closed system. (iodine in the tube, boiling water, wood burning, water vapor, weight loss, and gain or loss questions)
- The boundaries of physical and chemical changes are indefinite among students. (boiling water, wood burning, water vapor)
- In chemical changes gaseous reactants or products are disregarded and contribute to failing in conservation of mass. (wood burning, iron rust, weight loss)
- There is a disparity between chemical representation of atoms and molecules and students' fragmented, incoherent understanding of how molecules are composed of atoms. (boiling water, SO_3 formation, wood burning, iron rust, water vapor)
- Air fills every empty space even in atomic –molecular level. Similar to "ether theory" in 18th century alchemical thinking. (iodine in the tube, boiling water, Ice, gain or loss)
- Gas weighs lighter than solid or liquid form of the same amount of matter. (iodine in the tube, water vapor, weight loss, gain or loss)
- Matter transformations in either physical changes or chemical changes cause changes of mass. (iodine in the tube, SO_3 formation, wood burning, iron rust, water vapor, weight loss, gain or loss)
- Tracing of matter in atomic-molecular and cellular level changes fails to consider systems. (iodine in the tube, boiling water, SO_3 formation, wood burning, iron rust, water vapor, weight loss, gain or loss)
- Matter transformations within and between systems are inappropriately expressed as either matter-energy transformation or natural growth or decay. (weight loss, gain or loss)

Among above statements, the bottom three bullets refer to failures of systems thinking. Students have difficulties in recognizing conservation of mass in matter flow through systems because they don't understand systematic connection from atomic level understanding to macroscopic understanding of phenomena in environmental systems.

Interpreting relations of concepts and creating phenomenological categories

It is found that the relations in the clusters of students' conceptions describe five categories of conceptions relating to matter transformations in physical and chemical changes.

Our preliminary analysis of data indicates five main areas of concern in students' thinking about the matter in physical and chemical changes: a) properties of solids, liquids, and gases and explanations of those properties using atomic molecular model, b) macroscopic and microscopic transformations and properties in physical change, c) macroscopic and microscopic transformations and properties in chemical change, d) chemical representations of matter in atomic–molecular theory, and e) processes in matter-transforming systems such as sublimation, boiling and burning.

Table 5. Concept relations in five phenomenological categories

Properties of solid, liquid and gases with atomic molecular model

- Gas is not a matter and so has no mass. The law of the conservation of mass is not applied to any changes involving gas.
- Gas weighs less than liquids and solids.
- Air substitutes the gas produced during physical or chemical changes or the gas produced is mixed into air.
- Air fills empty space between the lattice points of crystalline structure or bubbles in the boiling water.

Macroscopic and microscopic transformations and properties in physical change (Tracing atoms and molecules in physical change)

- Physical parameters such as heat or pressure are considered as a part of matter transformations and cause the change of mass.
- Molecular structure of substances changes in physical changes.
- (Students cannot differentiate atomic-level and molecular level matter transformations.)
- Students tend not to use scientific terms directly to explain changes in bond distance, bond energy, and atomic-molecular motion according to the states of matter or in the process of physical change.

Macroscopic and microscopic transformations and properties in chemical change (Tracing atoms and molecules in chemical change)

- Majority of students showed superficial understanding of conservation of mass in case of burning, in which chemical change transforms solid matter into gases and some other solids. Despite the answer that nothing is destroyed when a piece of wood burns, most of the students can't trace the transformation of matter to gaseous matter form. 48.75% of students cannot predict iron rust can add the weight in spite of they were given the information that the rust came from oxygen and water from the air. 92.5% of students cannot trace the transformation to gaseous forms in weight loss question.
- Students' understandings are based on the concrete and observable changes and their explanations are mostly based on their common sense knowledge constructed when they attempt to make sense of their experiences. Examples) Wood burning is understood as change to ashes/smoke (70%), weight loss is understood as the transformation of fat molecules to muscle/protein or energy source (47.5%).
- Students cannot distinguish between physical and chemical changes, their definitions of them are ambiguous. 7.5% of students said wood burning simply involves phase change-they explain that in the burning no matter cannot be destroyed and just simply change the phases. – students understand burning as if it were physical change and mention conservation of mass as the validation of their reasoning.

Chemical representations of matter (particulate theory, use of atomic and molecular concepts to represent matter and matter change)

- misunderstanding of atomic-molecular theory
- misrepresentation of atoms and molecules in terms of atomic or molecular model
- The numbers of atoms which constitute a molecule involved in chemical reaction as a reactant or a product is misrepresented and confused with reaction coefficient.

Processes in matter-transforming systems – sublimation, boiling, burning

- No conservation of mass-lack of systems thinking, misunderstandings of particulate theory and chemical reaction
- caloric theory-students tend to think heat as a matter form
- no differentiation between physical and chemical change
- Ether theory-students tend to think that whenever gas is produced from any chemical reaction or physical change –for example, 27.5% of students think the bubble in the boiling water is air and 5% of students think the iodine gas from sublimation of solid iodine in a concealed tube is displaced by air. Students think air fills every invisible area of the atmosphere even between the ice crystal lattice points (52.5%)

Constructing and clustering core themes in the conceptual relations

The final stage of analysis enables us to construct the core issues in students' concept relations regarding environmental literacy theme in this study – matter transformations in physical and chemical changes in coupled human and natural systems. Students in this study were asked to predict or explain observations of physical and chemical changes in everyday or biological situation. High school chemistry students rarely used a particulate model appropriately. This was especially true when situations involved changes in and out of the gas phase. This shows in ways that they treated gases differently from solid and liquid materials.

Three characteristic properties that students attribute to solids or liquids, but not always to gases, are as follows: a) mass: students tend to treat gas as nothing and therefore having little or no mass, b) chemical identity: students tend to refer to gas as air or oxygen no matter what the actual gas is or where it comes from, and c) conservation of mass and chemical identity: students tend not to conserve mass or chemical identity in physical and chemical changes involving gases.

Mass of gases: Through the chemical and physical changes of matter by sublimation, boiling, rusting, and burning, gaseous substances are regarded as having less weight than the source material of liquids or solids.

Chemical identity of gases: Gaseous substance used as either reactant or product in chemical changes or involved in physical changes is often considered as air or forms mixture with air and is often confused with familiar gases such as oxygen or carbon dioxide.

Conservation of mass and chemical identity: Students do not view matter as being necessarily conserved between systems. When wood burns, matter burns away. When iodine sublimes some of the mass is lost. When a person loses body fat it disappears and some of it comes out of the body as solid or liquid form of matter. Students also tend to focus on the conditions or forms of energy such as heat or pressure and consider those conditions as a reactants or products of matter transformations between coupled environmental systems.

One interesting finding is that the developmental trajectory of knowledge acquisition from young childhood unraveled by numerous conceptual change researches appeared in the subject of this study and in considerable significant percentage in most concept areas examined. According to an evolutionary perspective on knowledge acquisition (Driver et al., 1994), the first important conceptual development is the notion of air or gas as a material substance. This is followed by an appreciation that the property of weight or mass is characteristic of all material substances and hence applies to bodies of gas as well as to solids and liquids.

Discussion

This study is done as a part of Environmental Literacy Project and we had five different working groups: physical & chemical changes, carbon cycle, water cycle, biodiversity & evolution, and connecting actions. Although each working group draws on separate data sources and reports separate analyses of results, we see the results of the different studies as tied together by several *big ideas* that play an essential role in reasoning about environmental systems. Each of the big ideas below has several qualities that make it important for environmental literacy.

The patterns in students' responses and limits to their understanding involve four of big ideas in general theme of environmental literacy that defined by the project team.

- **Model-based reasoning**

  Students often explain properties of materials or changes in materials in ways that rely on narrative reasoning and fail to make appropriate use of atomic-molecular models or principles such as conservation of mass. Less than half of students conserved mass. Students did not attribute equivalent mass to invisible gases and very often even phase change itself was misunderstood as becoming mixture of solid and gas or emitting various kinds of gases.

- **Tracing matter through systems**

  Students tend to think separately about human technological systems and natural environmental systems. They have difficulties tracing materials through matter transformations between systems, particularly when changes into or out of the gas phase are involved.

- **Connecting accounts of molecular, cellular, organismal, and environmental processes**

  Students often have difficulty tracing matter through physical and chemical changes, and connecting cellular or atomic-molecular level microscopic explanations to macroscopic organismal mass transformations. Appropriate classification of chemicals in different scales such as atomic-molecular, cellular, organismal distinction failed in identifying components of the mixture.

- **Quantitative reasoning with data and models**

  Many scientific models depend on and use complex patterns in data. These data are collected and displayed in many ways: tables, graphs, formulas, maps, etc. Thus students need to relate models to data through statistical, geographical, or other means. This big idea was not addressed in these results.

In conclusion, students' conceptions of matter transformation progress in general from perceptual categories such as referring familiar matters to systemic distinction of matter, substances, molecules and atoms. A large percentage of students still had difficulties in differentiating these particulate systems and understanding the conservation of mass in physical and chemical change. Applying particulate properties of matter into macroscopic systems, students' understanding of matter transformation differed in pattern according to the context.

Implications

Although the patterns in students' responses to individual questions resemble those reported in other studies, this study carries farther the analysis in developing a parsimonious explanation for those patterns. It appears that many of the responses are linked to a few fundamental misunderstandings about gases and changes in matter involving gases. If this is true, then addressing those basic misunderstandings may help students make significant progress. We hope to test this hypothesis through teaching experiments in the future. These misunderstandings have important implications for students' understanding of processes in environmental systems.

The view of matter conservation in these transformations constitutes a major change in students' ontology. This is particularly significant in relation to living things. Growth of living things is viewed as adding some mass and when an organism dies then some of the mass disappears. You can hardly find the connection between human and natural systems in matter transformation processes from students' reasoning. This vitalist ontology interferes with students' learning about a range of biological processes as a interacting systems with natural systems.

References

Advisory Committee for Environmental Research and Education. (2003, January). Complex Environmental Systems: Synthesis for Earth, Life, and Society in the 21st Century. National Science Foundation.

American Association for the Advancement of Science. (1989). Science for all Americans. New York: Oxford University Press.
[http://www.project2061.org/publications/sfaa/online/chap5.htm.]

American Association for the Advancement of Science. (1993). Benchmarks for Science Literacy. New York: Oxford University Press.

Anderson, C. W. (2003). Draft: Implications of Research in Children's Learning for Assessment.

http://scires.educ.msu.edu/Science05/Assets/802Files/Andy/Draft%20Report%20for%20Distributi.doc

Andersson, B. (1986). Pupils' explanations of some aspects of chemical reactions. Science Education, 70(5), 549-563.

Andersson, B. (1990). Pupils' conceptions of matter and its transformations (age 12-16). Studies in Science Education, 18, 53-85.

Barke, M. & Carr, M. (1989). Teaching and learning about photosynthesis. International Journal of Science Education, 11(1), 48-56.

Barker, S., & D. Slingsby. (1998). From nature table to niche: curriculum progression in ecological concepts. International Journal of Science Education, 20, 476-486.

Bell, B. (1985). Students' ideas about plant nutrition: what are they? Journal of Biological Education, 19(3), 213-218.

Berkowitz, A.R., M.E. Ford and C.A. Brewer. (in press). A framework for integrating ecological literacy, civics literacy and environmental citizenship in environmental education. In Johnson, E.A. and M.J. Mappin, editors. Environmental Education or Advocacy: Perspectives of Ecology and Education in Environmental Education. New york: Cambridge University Press.

Blank, L., & Brewer, C. (2003). Ecology education when no child is left behind. Frontiers in Ecology and the Environment, 7, 383-384.

Brewer, C. (2002). Conservation education partnerships in schoolyard laboratories: A call back to action. Conservation Biology, 16, 577-579.

Brumby, M. N. (1982). Students' perceptions of the concept of life. Science Education, 66(4), 613-622.

Bruner, J. (1985). Narrative and paradigmatic modes of thought. In E. Eisner (Ed.), Learning and teaching: The ways of knowing. Chicago: National Society for the Study of Education.

Bybee, R. W. (2003) Ecology Education when no child is left behind - Forum response. Frontiers in Ecology and the Environment **1**:389-390.

Carey, S. (1985). Conceptual Change in Childhood. Cambridge: MIT Press.

Conceptual Questions(CQs): Chemical Concepts Inventory, http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/CQs/ConceptsInventory/Concepts_Inventory.html

Driver, R., Guesne, E., & Tiberghien, A. (1985). Children's ideas in science, Milton Keynes: Open University Press.

Driver, R. A., Squires, A., Rushworth, P., & Wood-Robinson, V. (1994). Making Sense of Secondary Science: Research into Children's Ideas. NewYork: Routledge.

Finn, H., Maxwell, M., & Calver, M. (2002). Why does experimentation matter in teaching ecology? Journal of Biological Education

Gayford, C. G. (1986). Some aspects of the problems of teaching about energy in school biology. European Journal of Science Education, 8(4), 443-450.

Gometz Crespo, M. A., Pozo, J. I. & Sanz, A. (1995). Students' Ideas on conservation of matter: Effects of expertise and context variables. Science Education, 79(1), 77-93.

Gopnik, A., & Meltzoff, A. N. (1997). Words, thoughts, and theories. Cambridge, MA: MIT Press.

Leach, J., Driver, R., Scott, P., & Wood-Robinso,n C. (1996). Children's ideas about ecology 2: ideas found in children aged 5-16 about cycling of matter. International Journal of Science Education, 18, 19-34.

Lee, O., Eichinger D. C., Anderson C. W., Berkheimer G. D., & Blakeslee T. D. (1993). Changing middle school students' conspetions of matter and molecules. Journal of Research in Science Teaching, 30(3), 249-270.

Lee O., & Luykx A. (2003). Ecology Education when no child is left behind - Forum response. Frontiers in Ecology and the Environment 1:384-385.

Lehrer, R., & Schauble, L. (in press). Developing modeling and argument in elementary grades. In T. A. Romberg, T.P. Carpenter, & F. Dremock (Eds.), Understanding Mathematics and Science Matters. Mahwah, NJ: Lawrence Erlbaum Associates.

Marton, F., & Booth, S. (1997). Learning and awareness. Mahwah, NJ: Lawrence Erlbaum Associates, Publishers.

Marton, F. (1981). Phenomenography-describing conceptions of the world around us. Instructional Science, 10, 177-200.

McComas, W. F. (2003). The nature of the ideal environmental science curriculum. Advocates, textbooks, & conclusions (Part II of II). American Biology Teacher, 65, 171-178.

National Research Council. (1996). National Science Education Standards. Washington, DC: National Academy Press.

North American Association for Environmental Education. 1999. Excellence in Environmental Education - Guidelines for Learning (K-12). North American Association for Envioronmental Education (NAAEE), Washington, DC.

Nussbaum J. (1985). The particulate nature of matter in gaseous phase. In J. R. Driver, E. Guesne, & A. Tiberghien (Eds.), Children's ideas in science. Milton Keynes, UK: Open University Press.

Olson, M. (2005). Interns' Narrative and Paradigmatic Ways of Knowing Science. Unpublished doctoral dissertation, Michigan State University

Pozo, J. I., & Gomez Crespo, M. A. (2005). The embodied nature of implicit theories: The consistency of ideas about the nature of matter. Cognition and Instruction, 23(3), 351-387.

Smith, C., Maclin, D., Grosslight, L. and Davis, H. (1997) Teaching for understanding: A study of students' pre-Instruction theories of matter and a comparison of two approaches to teaching students about matter and density. Cognition and Instruction, 15 (3), 317-393.

Smith, C., Wiser, M., Anderson, C. W., Krajcik J., & Coppola B. (2004). Implications of research on children's learning for assessment: Matter and atomic molecular theory. Paper commissioned by the Committee on Test Design for K-12 Science Achievement. Center for Education, National Research Council.

Smith, E. L. & Anderson, C. W. (1984). Plants as producers: A case study of elementary science teaching. Journal of Research in Science Teaching, 21(7), 685-698.

Smith, E. L. & Anderson, C. W. (1986). Alternative student conceptions of matter cycling in ecosystems. Paper presented to National Association of Research in Science Teaching.

Stavy, R. (1990). Children's conception of changes in the state of matter: from liquid(or solid) to gas. Journal of Research in Science Teaching, 27(3), 247-266.

Stavy, R., Eisen, Y. & Yaakobi, D. (1987). How students aged 13-15 understand photosynthesis. International Journal of Science Education, 9(1), 105-115.

Stewart, J., Cartier, J. L., and Passmore, C. M. (2005). Developing understanding through model-based inquiry. In S. Donovan & J. Bransford (Eds.), How Students Learn: History, Mathematics, and Science in the Classroom. Washington, DC: National Academies Press, pp. 515-565.

Tamir, P. (1989). Some issues related to the use of justifications to multiple choice answers. Journal of Biological Education, 23(4), 285-292.

Vosniadou, S. (1994). Capturing and modeling the process of conceptual change. Learning and Instruction, 4, 45-69.

Wackernagle, M., & Rees, W. (1996). Our ecological footprint: Reducing human impact on the earth. New Society Publishers, Gabriola Island, B. C., Canada.

Appendix A : Test

Physical and Chemical Change Pretest
(Middle and High School)

Science is easier to understand if you can make connections between what you know now and the new ideas that you are studying. This is a test that will help us to understand what you know now. These questions are about one of the topics you will study this semester—the nature of gases and how they change.

Please answer these questions as carefully and completely as you can. If you aren't sure of the answer, please write about any thoughts that you have. If you can help us to understand how you think about these questions, then we can do a better job of explaining chemistry in ways that make sense to you.

Name ______________________________________ Date _______________

Class __________________________ Teacher

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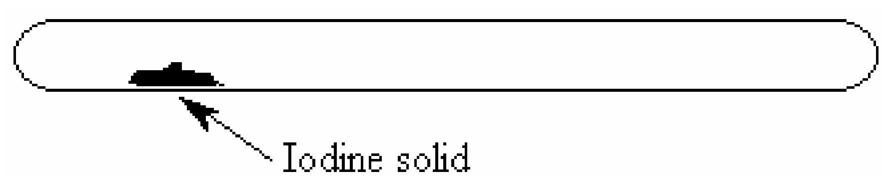
1. A 1-gram sample of solid iodine is placed in a tube and the tube is sealed after all of the air is removed. The tube and the solid iodine together weigh 27 grams.



The tube is then heated until all of the iodine evaporates and the tube is filled with iodine gas. Will the weight after heating be:

a. less than 26 grams.

b. 26 grams.

c. between 26 and 27 grams.

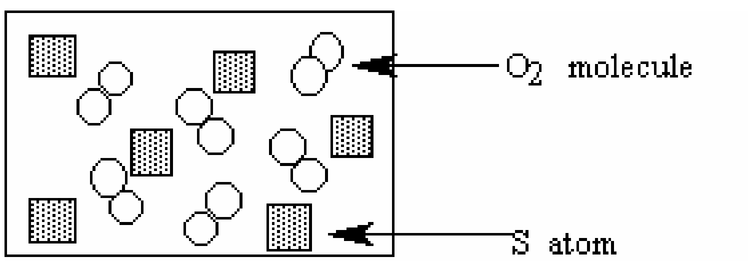
d. 27 grams.

e. more than 27 grams.

2. What is the reason for your answer to question 1?

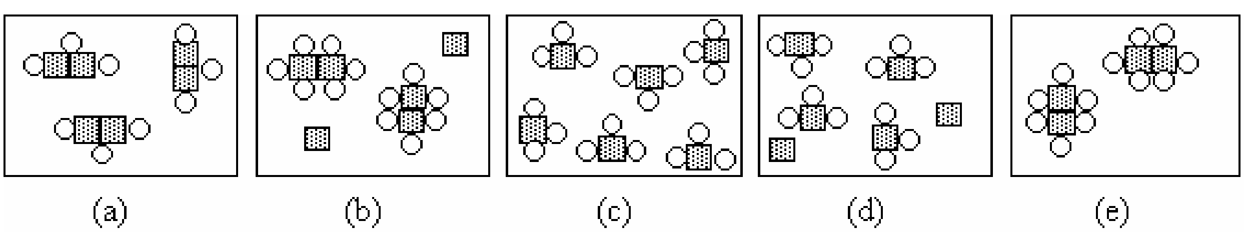
3. Assume a beaker of pure water has been boiling for 30 minutes. What is in the bubbles in the boiling water?

4. The diagram represents a mixture of S atoms and O_2 molecules in a closed container.



Which diagram shows the results after the mixture reacts as completely as possible according to the equation:

2 S + 3 O_2 --> 2 SO_3



5. True or False? When a piece of wood burns, some matter is destroyed.

a. True

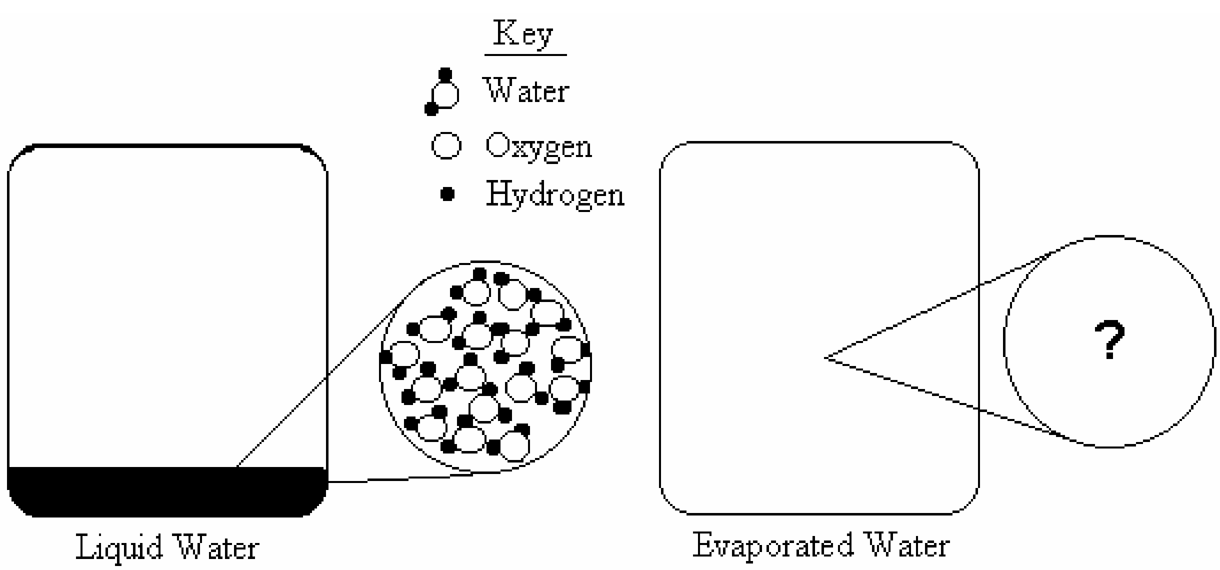
b. False

6. What is the reason for your answer to question 5?

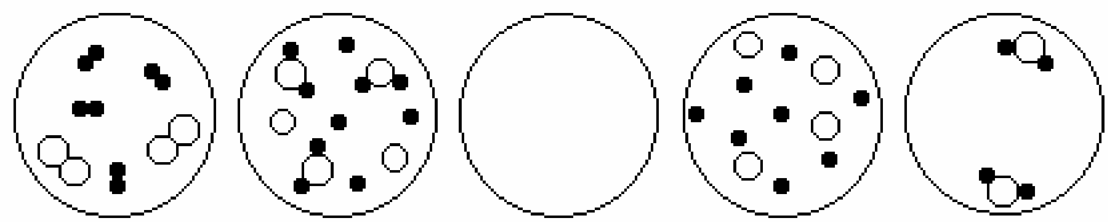
7. Iron combines with oxygen and water from the air to form rust. If an iron nail were allowed to rust completely, one should find that the rust weighs:

a. less than the nail it came from.
b. the same as the nail it came from.
c. more than the nail it came from.
d. It is impossible to predict.

8. The circle on the left shows a magnified view of a very small portion of liquid water in a closed container.

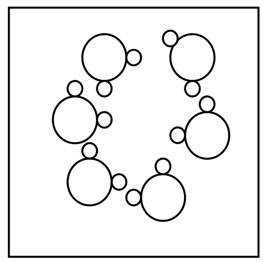


What would the magnified view show after the water evaporate?



(a) (b) (c) (d) (e)

9. This drawing represents the atomic-molecular model of a piece of ice.



What is in between the molecules?

a. Nothing (vacuum)

b. Air

c. Water

d. Ice

10. What makes ice harder than liquid water?

11. A person on a diet lost 20 pounds. Some of his fat is gone. What happened to the mass of the fat?

12. When you roll a ball of clay into a rope, the clay gains length even though nothing is added or taken away. When you place water in a refrigerator for a while, water loses volume even though nothing is added or taken away.

Is there anything that can gain or lose weight though nothing is added or taken away? (You can think about living things like plants and animals as well as non-living materials like clay.)

Choose yes or no. Yes___ No____

If you chose Yes, explain why, and give examples if you can.

If you chose No, explain why.

Endnote:

Questions 1, 2, 3, 4, 5, 6, 7, 8,

Conceptual Questions (CQs): Chemical concepts Inventory.

http://jchemed.chem.wisc.edu/JCEWWW/Features/CQandChP/CQs/ConceptsInventory/Concepts_Inventory.html

Questions 9, 10

Draft: Implications of Research in Children's Learning for Assessment.

http://scires.educ.msu.edu/Science05/Assets/802Files/Andy/Draft%20Report%20for%20Distributi.doc