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Students' understanding of connections between human engineered and natural environmental systems

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This research draws on developments in educational research where *learning progressions* are emerging as a strategy for synthesizing research on science learning and applying that research to policy and practice, and advances in the natural sciences, where *interdisciplinary research on coupled human and natural systems* has become increasingly important. It focuses on the human systems that supply all of our essential goods and services (i.e., food, water, transportation), which begin and end in the earth's natural systems. In order to investigate what students know about how human actions affect environmental systems, we developed assessments focusing on *supply and waste disposal chains*. In addition, students were asked about a major environmental issue – global warming. Assessments were administered to elementary, middle, and high school students from rural, suburban, and urban schools. Results from this study provide insight into how student knowledge of connections between human-engineered and natural systems varies across grade level and context, which is essential if we are to teach students to be responsible citizens and stewards of our environment.

Keywords: connected natural and human-engineered systems, environmental science literacy, K-12 science curriculum, student understanding

Introduction

Reform efforts that argue for interdisciplinary science, attempt to make science relevant for students by connecting science to students' daily lives, and support the goal of creating responsible citizens are not new - these are goals of both the Science, Technology and Society (STS) and Socioscientific Issues (SSI) reform efforts and part of the *National Science Education Standards* (National Research Council, 1996) and *Science for All Americans* (American Association for the Advancement of Science, 1990). As Aikenhead (1994) purports, "STS instruction aims to help students make sense out of their everyday experiences, and does so in ways that support students' natural tendency to integrate their personal understandings of their social, technological, and natural environments" (pp. 48-49). The SSI movement has a growing body of research (cf., Sadler, 2004; Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006; Sadler & Zeidler, 2004; Zeidler, Sadler, Applebaum, & Callahan, 2009; Zeidler, Sadler, Simmons, & Howes, 2005; Zeidler, Walker, Ackett, & Simmons, 2002). The SSI movement also focuses on real-world applications and the roles of science and technology in society by focusing on socioscientific issues such as genetic engineering and environmental issues, but it diverges from

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STS with its explicit attention to ethical aspects of social issues that are tied to science (Sadler et al., 2006).

This research draws on aspects of and fits within the goals and efforts of both the STS and SSI movements. It extends upon these efforts by incorporating developments in educational research where *learning progressions* are emerging as a strategy for synthesizing research on science learning and applying that research to policy and practice (Anderson et al., 2006; Duschl, Schweingruber, & Shouse, 2007; Smith, Wiser, Anderson, & Krajcik, 2006). *Taking Science to School*, a National Research Council Report on teaching and learning science, states that "Learning progressions are descriptions of successively more sophisticated ways of thinking about a topic that can follow one another as children learn about and investigate a topic over a broad span of time" (Duschl et al., 2007, p. 219). The report argues that learning progressions should be grounded in the knowledge and reasoning about a concept that students bring to the classroom. The other end of a learning progression is anchored in "societal expectations", or in terms of learning targets – what students should know by the end of their K-12 learning experiences.

In addition, it draws on advances in the natural sciences, where *interdisciplinary research on coupled human and natural systems* has become increasingly important (see, for example, AC-ERE: NSF Advisory Committee for Environmental Research and Education, 2003). A report from the United States Environmental Protection Agency states that, "there is a growing consensus, both within and outside the Agency, that a more integrated approach to environmental management is needed. …[A] piecemeal approach ignores the integrated manner in which hazards occur… may cause us to overlook significant environmental problems" (U.S. Environmental Protection Agency Science Advisory Board, 2000, p. 2). Global and intergovernmental projects that survey the state of the environment and establish a scientific basis for action and policies that must be undertaken regarding conservation and sustainable use of ecosystems consist of committees of scientists from many disciplines and social scientists (i.e., Intergovernmental Panel on Climate Change [IPCC], 2007; Millennium Ecosystem Assessment, 2005). Many of these interdisciplinary efforts have arisen because of the growing understanding of how humans are altering local and global environments.

These developments in science have crucial implications for how students are taught science in schools. As humans continue to have greater and greater impacts on our environments, it is vital that students learn more about how humans affect their environments. This article reports the results of an exploratory study of elementary, middle, and high school students from rural, urban, and suburban schools understanding of the connection between human engineered and environmental systems. It does this through investigating student understanding of three large-scale supply and/or waste disposal chains systems and one environmental issue that is impacted by supply and waste disposal chains.

Theoretical Background

Environmental Science Literacy

Humans live in and impact their environment, but often know little about how their actions impact it and how the decisions they make affect their impacts. A report by the Ecological Society of America (ESA) states that, "Environmental issues will define the 21st Century, as will a world with a large human population and ecosystems that are increasingly shaped by human intervention" (Environmental Visions Committee, 2004, p. 2). The ESA argues that the public must be educated so that ecological knowledge informs human choices about sustainability.

Environmental issues such as global warming and sustainable agriculture have received much attention in the popular media through forms such as Al Gore's documentary, "An Inconvenient Truth" (Guggenheim, 2006), Michael Pollan's (2006) book, *Omnivore's Dilemma* and Thomas Friedman's (2008) book, *Hot, Flat and Crowded* – all attempts to inform the public about the role that humans play in environmental issues.

While more people are increasingly becoming aware of environmental issues, "Each of the NEETF/Roper studies from 1997 through 2001 found that Americans have low levels of knowledge on basic environmental facts, underlying science, causes of certain conditions, and important public environmental issues" (Coyle, 2005, p. 3). Furthermore, the report argues:

> …environmental education is more about understanding important causal relationships – what might cause air and water pollution, the ramifications of recycling… and about an individual's ability to sort out those connections. This understanding of causal connection is the single biggest problem in the environmental knowledge gap. The NEETF/Roper studies show that most people grasp simple one-step causes of problems easily enough. The majority can, for example, understand that a car pollutes the atmosphere or a factory can pollute a stream. But add a couple of complicating steps to the process (a car deposits small amounts of oil on the ground and rain washes it into a drain that eventually goes to a stream), and understanding drops off steeply. Few people seem to grasp multi-step causal relationships… (p. 14)

The heightened attention given to environmental issues but low levels of understanding about these issues signifies the increasing need for the public to be able to draw upon their knowledge of different branches of science (i.e. carbon chemistry, weather systems, genetics), how these branches of science are connected and part of the ecosystem, and how their actions impact the ecosystem in order to make informed decisions about environmental policy issues (i.e., global warming, agriculture, fuel emission testing, recycling). The integration of science disciplines is all the more important due to the nature of environmental problems – they do not necessarily abide by traditional discipline boundaries - and the scale of environmental problems such as global warming.

There are many gaps in our understanding of how students reason about environmental issues. Kempton et al.'s study (1995) of American environmental values and beliefs suggests that naïve understandings of environmental systems influences behavior. Americans often inappropriately apply cultural models (models shared within a culture) to support policy positions that are likely to be ineffective. For example, Kempton (1997) found that the public believed that air pollution is caused by artificial chemicals as opposed to natural substances, and that ozone depletion is the cause of global climate change. When Americans do not hold correct understanding of scientific, data-driven models, they can not make responsible choices regarding their own actions and environmental policies.

We have set forth the agenda of teaching students to be environmentally literate, where students understand how human engineered and natural systems are connected and how they impact their environment. We define environmentally literate students as environmentally responsible students who are capable of thinking in an interdisciplinary/ecological manner and of using scientific reasoning as a resource for personal and social decision making. This means that students need to engage in three key practices of environmental science literacy (Anderson et al., 2008; Anderson et al., 2006):

Practice 1. scientific inquiry

Practice 2. scientific accounts, and
Practice 3. scientific reasoning

The first practice, scientific inquiry, calls for students to be able to learn from experiences and be able to develop and evaluate scientific arguments from evidence. Students must be able to evaluate evidence, which includes assessing the validity and reliability of the evidence. The second practice, using scientific accounts, refers to students' ability to use scientific accounts of the material world to explain a scenario and to predict likely outcomes of different courses of actions. For example, in a hamburger supply chain, an environmentally literate student should be able to explain the supply chain that brings hamburger meat from the farm to the table. She or he should also be able to predict how different choices, such as how the cow is fed, how the meat is processed or how the meat is transported affect the material world. Finally, an environmentally literate student should be able to use scientific reasoning in citizenship practices of environmental decision-making. Students play various public and private roles in society, including the role of a voter, advocate, volunteer, consumer, owner, worker and learner throughout their lifetimes. We envision scientifically literate students as those who are aware of the environmental consequences of their actions. They draw on their understanding gained through scientific inquiry and accounts in order to make informed decisions.

Connecting Human Actions with Environmental Systems

This particular article, which is part of the larger environmental science literacy project, focuses on what students know about connections between human engineered and environmental systems. Some research exists on students' understanding of environmental issues such as global warming (Andersson & Wallin, 2000; Boyes & Stanisstreet, 1998; Boyes, Stanisstreet, & Papantoniou, 1999; Francis, Boyes, Qualter, & Stanisstreet, 1993; Jeffries, Stanisstreet, & Boyes, 2001; Lester, Ma, Lee, & Lambert, 2006) or air pollution (Myers, Boyes, & Stanisstreet, 2000; Myers, Boyes & Stanisstreet, 2004). Leeming and Dwyer (1995) constructed the Children's Environmental Attitudes and Knowledge Scale (CHEAKS) to assess students' attitudes and knowledge about the environment. But these studies, for the most part, do not ask questions that get at students' understanding of the processes or connections involved in coupled human and natural systems. Shepardson and his colleagues (2007) examined students' mental models of the environment and found that most students picture the environment as a place where animals and plants live, but do not include humans in this conception. This study begins to investigate how students see themselves as connected to the environment, but does not ask students about their understanding of connections between human engineered and environmental systems. Calabrese Barton et al. (2005) reported on a qualitative study of what high poverty urban children understand and believe about food and food systems, which was one of the few studies that we found that examined students' understanding of the connections and processes involved in a coupled human and natural system, in this case the food system.

More research is needed about what students know about how human engineered and environmental systems are connected and how human actions affect environmental systems. This research focuses on connecting human actions to environmental systems. In particular, it focuses on a particular class of human actions: Our actions as consumers of essential goods and services, including food, clothing, shelter, air, water, and transportation. Goods and services in each of these categories pass through a number of environmental systems on their way to us (the supply chain) and go through additional systems after we are done with them (waste disposal). The human systems that supply all of our essential goods and services begin and end in the earth's natural systems. Therefore, we developed an assessment that focuses on supply and waste disposal chains and the connection between human engineered and natural systems. We focused on the second and third key practices of environmental science literacy. We were interested in the following questions:

- How aware are students of food supply chains and waste disposal chains? (Practice 2)
- What do students know about the origin of goods and services they use in their daily lives and the impact that these goods and services have on the environment? (Practices 2 and 3)

This article builds on previous work for this project which analyzed student understanding of supply and waste disposal chains and environmental issues (Anderson et al., 2006). The first study examined a smaller sample of students from mainly rural schools. This article examines results from a larger sample of elementary, middle, and high school students from rural, suburban and urban schools. We felt that context may play an important role in student experiences, and therefore, their knowledge of how humans are connected to environmental systems. For example, rural students may have more or different experience with some food supply chains than urban and suburban students. In addition, we were interested in developing a learning progression. Thus, we were also investigated the questions:

- Does student understanding of supply and waste disposal chains and their effects on environmental systems differ due to context (rural, suburban, urban)?
- How does student knowledge of supply and waste disposal chains and their effects on environmental systems differ by grade level (elementary, middle, high school)?

Methods

Participants

A total of 16 teachers from 14 different public schools (6 high school, 6 middle school, 4 elementary school) in one Midwestern state administered the assessment. The assessments were administered between October 2005 and April 2006. The paper and pencil assessments were given during the regular class day. The teachers did not provide any formal classroom instruction about supply and waste disposal chains or climate change prior to administration of the assessment. The assessment is described in more detail below. The students were provided with enough time to fully complete the assessment, which typically took students approximately 45 minutes. A total of 723 students participated, which included 125 elementary school students, grades 4-5 (34 rural, 46 suburban, 45 urban); 371 middle school students, grades 6-7 (40 rural, 181 suburban, 150 urban); and 227 high school students, grades 9-12 (47 rural, 100 suburban, 80 urban) (see Appendix A for more information). We used a cross-sectional data collection because we were interested in how students' knowledge of supply and waste disposal chains and their effects on environmental systems differed by grade level (elementary, middle, high school), rather than looking at changes in students' learning over time due to instruction. This is similar to other learning progression work conducted as part of the larger research project (Mohan, Chen, & Anderson, 2009).

Assessment

The assessment was not designed around a particular curriculum taught in the schools. While students in the United States usually learn about food chains and food webs (NRC, 1996) and may conduct reports on topics such as deforestation to study the impact of humans on natural environments, they do not often specifically learn about supply chains and waste disposal chains as a means of understanding connections between human engineered and natural environmental systems. We, however, similar to Coyle's (2005) report on *Environmental Literacy in America*, argue that students must be able to make connections between human engineered and natural systems and the processes involved that connect, or intertwine, the systems. Thus, in our study we were particularly interested in students' understanding of supply and waste disposal chains that connect our consumer products to the natural environment and developed an assessment to ascertain this.

Humans take matter and energy from natural systems and return them (often in different forms) back to natural systems on a daily basis, whether it is oxygen and carbon dioxide, water, food, or materials such as wood. Various human engineered and natural systems interact at each step of supply and waste disposal chains. Thus, the assessment questions were designed to elicit student understanding of three *large-scale systems and processes*: a hamburger supply chain, a paper cup waste disposal chain, dishwashing supply and waste disposal chain. It also asks students about one *environmental issue*, global warming, that is impacted by supply and waste disposal chains. For example, humans take fossil fuels from the environment, process them for products such as gasoline, and use gasoline in order to run cars and other machines which results in carbon dioxide emissions that contribute to global warming.

The assessment was developed over a two-year period, from 2004-2006. We developed opened-ended questions, asking students to trace the supply chain of products as far as they could back towards the product's origins, or the waste disposal chain forward as far as they could for waste that they throw away. We chose to ask open-ended questions in order to ascertain students' ideas; we were interested in the answers that the students generated without pointing them in a specific direction. The assessment was piloted during the 2004-2005 school year with a smaller sample of 34 fourth grade students, 26 sixth grade students, and 44 ninth and tenth grade students. The assessment was revised based on results from the pilot study (Tsurusaki & Anderson, 2006). Data from the 2005-2006 school year were analyzed and reported in this paper.

For the purposes of this paper, one supply chain question and one waste disposal chain question were analyzed: 1) Where did the hamburgers come from? and 2) How would you get rid of a paper cup and what might happen to it? We situated the hamburger supply chain question in terms of students' school lunch. We chose the hamburger supply chain because most students are familiar with hamburgers. The question included the following information: "You go through the lunch line at school and see that they are serving hamburgers. Where did the hamburgers come from? The ground beef in the hamburger patties wasn't always ground beef. It wasn't even always beef." The students were then asked to trace the beef back as far as they could and provide their ideas about what it was and where it came from before it came to the school cafeteria. For the waste disposal question, we chose a paper cup because it is also something that students are familiar with. This question contained two parts: Part A, After you finish drinking some water from a paper cup, how would you get rid of the cup?, and Part B, What do you think might happen to this cup once it leaves your hands? The students were asked to trace the waste disposal chain as far forward as they could. In addition, we asked students if there could be any connection between hamburger and a corn field and between a tree and a paper cup and to provide a rationale for their response[1].

While students were specifically asked to trace the supply chain of hamburger meat and the waste disposal chain of a paper cup, another question asked students to list the resources that are used when handwashing and using a dishwasher to wash dishes, and the impact that using these various resources have on the environment. This question did not give students the products and ask them to trace the supply or waste disposal chain; students had to provide the resources that are used and determine their impact on the environment. Thus, the question indirectly asked students to trace the supply chains or waste disposal chains of various resources used when washing dishes.

Finally, a question about a major environmental issue that consisted of three parts was analyzed. First, students were asked if they have ever heard of global warming or global climate change, then they were asked if they knew what causes global warming, and finally, they were asked what could help reduce global warming. The purpose of this question was to discover how aware students are of a major environmental issue and what they know about it.

Data Analysis

Procedures

Analysis was guided by a Working Paper which contains rubrics for coding students' responses (Tsurusaki, 2006). Emergent codes were developed for the open response items from analyzing a sample of twenty assessments. These codes were then further revised based on the analysis of a second sample of twenty assessments. Reliability of the rubrics was assessed by having a second coder independently code a sample of assessments. When there were discrepancies, the rubrics were revised until at least 90% reliability was achieved.

We then looked for patterns in the types of responses, or codes, that students provided. These patterns in the codes were used to help develop a framework for supply and waste disposal chains.

Framework

This framework was developed through an iterative process. We examined student responses to the questions and also considered what we would want students to know (upper anchor of learning progression) about supply and waste disposal chains, which resulted in the following framework.

In order to assess the environmental impact of goods and services, students need to trace matter and energy through large-scale engineered systems, as much of our goods and services are produced and supplied via large-scale systems. Students must recognize that these systems include various actors (i.e., farmers, truck drivers, factory workers) and locations/places (i.e., store, farm, landfill), the infrastructure that supports these supply and waste disposal chains (i.e., trucks, roads, pipes) and their by-products (i.e., fossil fuel emissions). Figure 1 shows a very simplistic version of a hamburger supply chain. The transportation arrows represent the idea that there is transportation involved in each step of the food supply chain. For example, transportation is involved in moving the grain to the cattle, whether it is from the same farm or a different farm. It is also necessary to transport by-products away from the cattle and to move the cattle from the ranch to the feedlot.

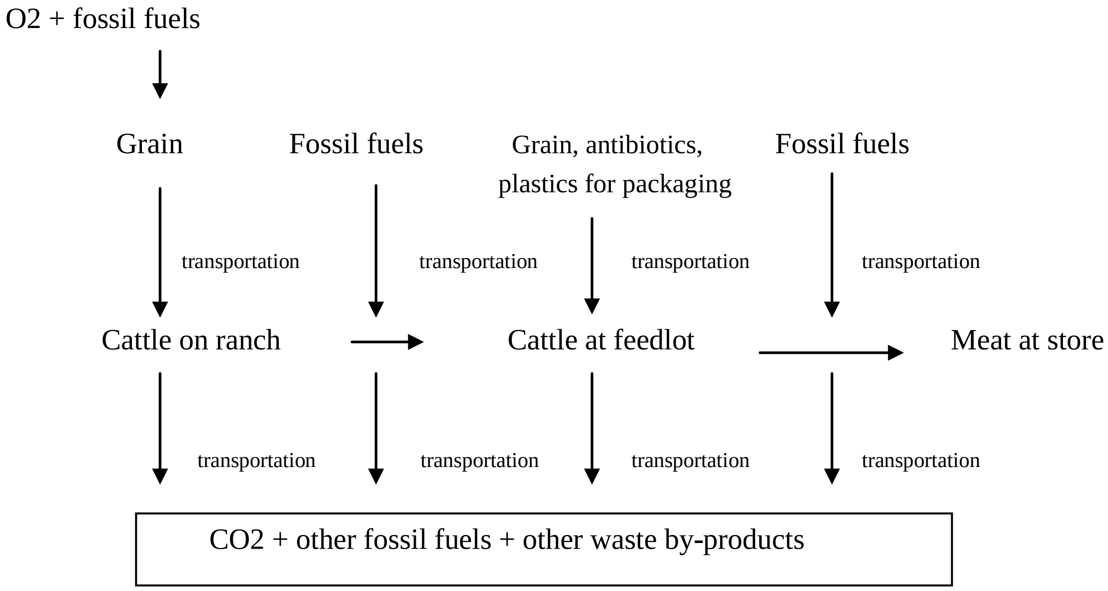

Figure 1. Simple diagram of a hamburger supply chain
[This diagram does not include labels with actors, as it is difficult to represent in the diagram]

Thus, students need to be able to trace matter and energy through various actors and places across the boundaries between engineered and natural systems and the by-products produce by the systems. While this example portrays a supply chain, the same framework can be applied to waste disposal chains. In waste disposal chains, there are also actors and locations/places, the processes/transformation of mater and energy, and infrastructure and by-products. Using this framework as a guide, the assessments were analyzed by examining the actors and locations/places, the processes/transformation of matter and energy and the infrastructure and by-products students mentioned in their responses.

Statistical Analysis

SPSS was used to perform the statistical analysis. For all questions, frequency counts were tabulated and percentages of students per elementary, middle, and high school, and overall, were calculated. For example, in the hamburger supply chain, the number of students who mentioned "butcher", "farm", "factory" etc., as part of the supply chain was tabulated and divided by the total number of students who responded to the question (see Tsurusaki, 2006 for detailed information about the codes). One-tailed significance of the difference between two independent proportions tests were conducted to determine the significance between students answers according to level (elementary, middle, and high school) and context (rural, suburban, and urban). For example, the proportion of urban students who mentioned that there was a connection between a paper cup and a tree was significantly less than the proportion of suburban students ($p < 0.05$).

In addition, total number of "steps", or codes,[2] per student was calculated, and a chi-square test was run to determine association between number of steps students mentioned and the level of school (elementary, middle, high) and context (rural, suburban, urban). For the hamburger supply chain, students mentioned between 0 and 8 steps. Students with 0 steps were not missing data - they responded to the question, but their answer(s) were coded as unintelligible, and thus were not counted in the number of steps listed. In order to run the chi-square, the number of steps students mentioned were broken into three levels: low = 0-3 steps, medium = 4-5 steps, and high = 6-8 steps. For the paper cup waste disposal chain students recorded fewer steps, between 0 and 6 steps, which were broken into three groups: low = 0-2, medium = 3-4, and high = 5-6.

Findings and Discussion

Our research questions lead to interest in two ideas about student understandings:

1. Students' understanding of how we are dependent on natural systems
2. Students' understanding of the environmental impacts of our actions

Therefore, we will discuss the student responses according to two questions:

1. Which connections between human and natural systems are commonly mentioned by students and which are not?
2. What awareness do students show of the human actions that have the greatest environmental impact?

In the results section, we first discuss the connections between human and natural systems that students mentioned. We begin with a general discussion of student understanding of where human engineered and natural systems connect at the beginning of supply chains and the end of waste disposal chains. Then we continue the discussion based on the following themes from our framework (Figure 1):

- *Actors and location/places:* Actors and location/places play an important role in supply and waste disposal chains. It is important to recognize the actors and locations/places students mentioned and those they left out.
- *Infrastructure:* Systems and processes require infrastructure that connects various steps or stages of the systems and processes. What aspects of infrastructure did students mention?
- *Processes/Transformation of matter and energy:* What matter did students mention? Did students mention energy? Did students simply mention matter as it moved from location to location, or did they also mention the transformation of matter and energy as it passed through various human engineered and natural systems?

In the next section, Human actions and environmental impact, we address student understanding of the impact human actions have on the natural environment. We talk about how some steps of supply and waste disposal chains may be "invisible" to students. This invisibility prevents them from understanding the impact various processes involved in supply and waste disposal chains have on the environment. In the final two sections of the discussion, we summarize similarities and differences in student understanding across grade level and context.

Connections between Human and Natural Systems

It is important for students to understand that the products and services we use start from and end up in natural systems. In the hamburger supply chain, more than 88% of students traced the hamburger meat back to the cow or some type of animal, and almost half of all students mentioned a farm where the cow lives (see Figure 2). For example, one elementary student wrote that before the ground beef was a hamburger in the cafeteria, it was:

> From the store.
> [Before that] A buchter [sic] store
> [Before that] A fram [sic]
> [Before that] from a cow

Thus, most students connected the human engineered food production system (beef) with the natural system (living animals). Some students recognized the life cycle of animals; 21.1% of all students mentioned some type of growth of the cow (mentioned both a calf and a cow, but did not necessarily state that the cow "grows"). But only 5.6% of all students mentioned plants (primary producers) or food that the cow ate in order to grow and no students mentioned how the plants grow. For example, one high school student traced the supply chain back to "A cow grazing in a field". When students were asked if there could be any connection between hamburger meat and a corn field, 63.6% of all students answered yes. 29.1% of all students gave the reason for the connection as "Cows eat corn" or "Meat comes from cows and cows eat corn" (code B), without

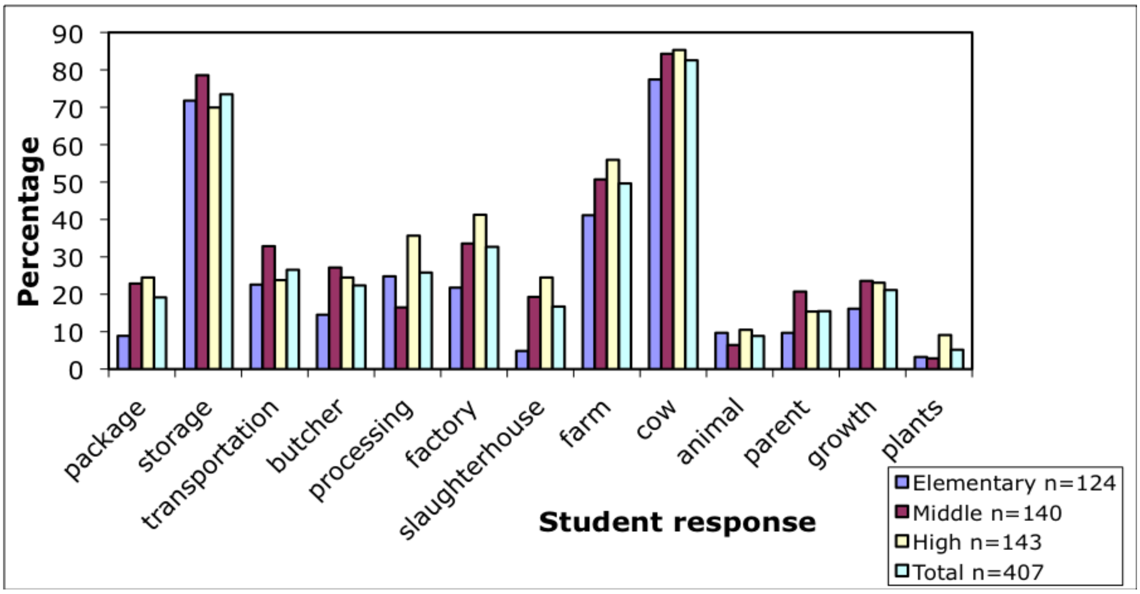

Figure 2. Percentage of elementary, middle, and high school students who mentioned steps of hamburger supply chain

mentioning why cows eat corn (Table 1). Yet students did not include corn or plants that the cows eat in order to grow in their depictions of the hamburger supply chain.

While food chains and producers, consumers, and decomposers are often part of the science curriculum in the US (National Research Council, 1996; AAAS, 1993), students did not often make these connections in the hamburger supply chain in this open-ended question. One might

Table 1. Percentage of student responses to why hamburger and corn could or could not be connected

Part A response	Code	Characteristics of student answers	Level (percentage)			Context (percentage)			Total (%) n=412
			E n=125	M n=140	H n=147	R n=121	S n=146	U n=145	
Yes	A	Yes – mentioned *why* cows might eat corn; specifically relate eating corn to growth of cow	1.6	0.7	4.1	2.5	2.7	1.4	2.2
Yes	B	Yes – cows eat corn, but do not mention *why*	12.8	27.9	44.2	36.4	35.6	16.6	29.1
Yes	C	Yes – cows on *same farm*, but no connection between cows eating corn or both cows are raised on farms and corn is grown on farms	16.8	18.6	14.3	14.9	19.2	15.2	16.5
No	D	No – corn is not the same thing as meat	31.2	19.3	15.6	18.2	19.2	26.9	21.6
No	E	No – no relationship; states that there isn't a relationship, but doesn't give any further explanation as to why	4.0	3.6	2.0	2.5	2.1	4.8	3.2
No	F	No – cows eat grass	0.0	2.9	3.4	3.3	0.0	3.4	2.2

*Answers not included in table were coded as no response, other (not enough similar answer to constitute a category), or unintelligible.

argue that students could make this connection when prompted, such as in the question asking students about the connection between a corn field and cow, but it is important for students to make connections in natural systems and between human engineered and natural systems without specific prompting if we hope for students to be able to apply their knowledge to real life context outside of school.

When students were asked if there could be a connection between a paper cup and a tree, 93.4% of students recognized that there could be a connection. The most common reason given for the connection was that paper is made from trees, code C (73.3% of all students) (Table 2). For example, one high school student wrote:

> Paper is made from trees.

Table 2. Percentage of student responses to why a paper cup and a tree could or could not be connected

Part A response	Code	Characteristics of student answers	Level (percentage)			Context (percentage)			Total (%) n=412
			E n=125	M n=140	H n=147	R n=121	S n=146	U n=145	
Yes	A	Yes – mentioned *pulp* or a *process*	*0.8*	*5.0*	*8.1*	5.8	6.8	2.1	4.9
Yes	B	Yes – specifically mentioned the *wood* of the tree, does NOT mention a process	5.6	5.8	4.1	6.6	5.5	3.4	5.1
Yes	C	Yes – paper made from trees – does not mention wood or process	72.8	69.8	77.0	71.1	72.6	75.9	***73.3***
Yes	D	No – no additional information give other than because it is paper	0.0	1.4	0.0	1.7	0.0	0.0	0.5
No	E	No – no connection	2.4	5.0	0.0	3.3	0.7	3.4	2.4

*Answers not included in table were coded as no response, other (not enough similar answers to constitute a category), or unintelligible.

Some students stated that paper cups are made from the "wood" of trees, code B (5.1% of all students) and a small proportion mentioned "pulp" or some type of "process", code A (4.9% of all students). For example, one high school student wrote:

> Paper is made from wood pulp, tree is processed, then the paper is used to make the cup, cup lined with wax.

Students acknowledge that paper is made from trees; paper comes from natural systems. Students who traced the trash waste disposal chain for the paper cup sometimes ended with the cup decomposing in a landfill (30.5% of all students tracing the trash waste disposal chain) (see Figure 3). For example, one high school student wrote that after the paper cup was in a trash can, it was:

> Brought out to the side of road
> [Then] picked up by trashmen
> [Then] drive to landfill
> [Then] dumped in landfill
> [Then] Decomposes in ground

Thus, the paper cup is reentering back into a natural system. While students may not understand the constraints human engineered systems have placed on natural processes, in this case the structure and function of landfills, they are aware that waste reenters natural systems. For the students that traced the recycling waste disposal chain, students most commonly ended the chain by stating that a new product was created. For example, one middle school student wrote that after the cup was thrown in the trash, it:

[Went to the] dump
[Then it was] crushed
[Then it was] recycled in a new cup
[Then it was] back in store

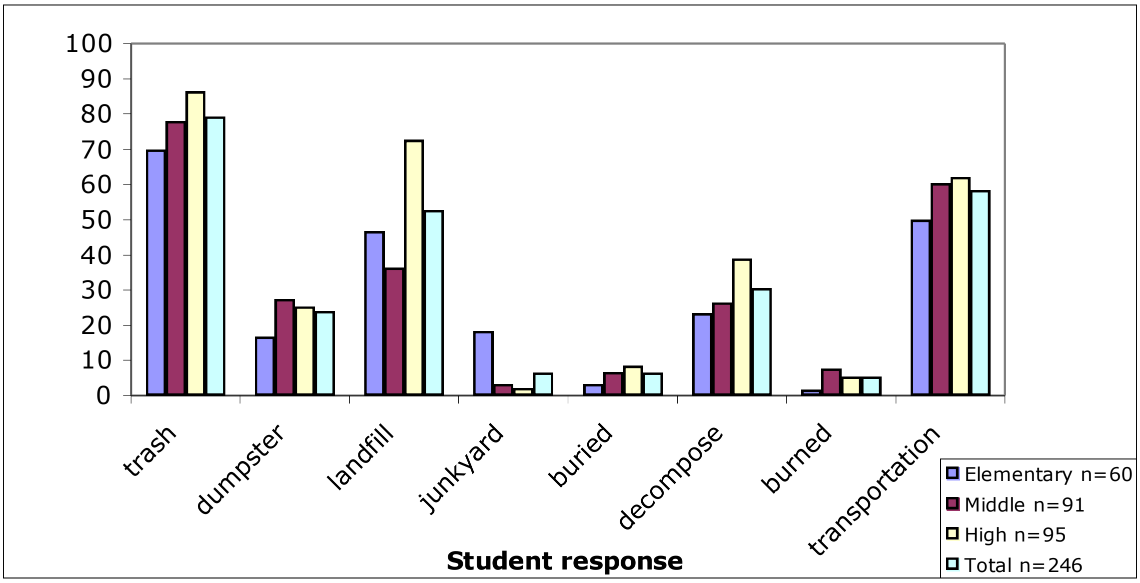

Figure 3. Percentage of students who mentioned steps of trash waste disposal chain

In this case, the paper cup did not reenter a natural system.[3] Tracing the hamburger supply chain back to the cow or animal the meat comes from and recognizing that paper is made from trees is a good start to understanding the connections between human engineered and natural systems.

Actors/Locations/Places

While understanding of some connections between human engineered and natural systems is a good start, we believe that students need to know that natural and human engineered systems interact at more than just the beginning and end of supply and waste disposal chains. Students need to understand the various actors and places (both natural and human engineered) involved with each step and how they are connected to each other through infrastructure.

Students typically depicted supply and waste disposal chains as sequences of locations/places. For example, for the hamburger supply chain, students' storylines often proceeded as follows: Before it was hamburger meat in the cafeteria, it was hamburger meat at a "store". Before that it was hamburger meat at a "factory". Before that, the hamburger meat came from a cow on a "farm". The hamburger meat supply chain seems to be built around an image of a small-scale rural production on family farms rather than large-scale industrial beef production. Thus, farms are in almost all students' supply chains, while feedlots are in none.

Students also described the paper cup waste disposal chain as a series of locations/places. A typical student's garbage waste disposal chain stated that the student would first throw the paper cup in the "trash can", then the trash can would be dumped into the school "dumpster", and a "garbage truck" would take the trash to a "landfill". For a recycling waste disposal chain, students usually stated that the cup would be thrown in a "recycling bin", and then it would be transported to a "recycling center", where it would be made into a "new cup" or product. Thus, students focused on places – trash cans, dumpsters, landfills, recycling bins, and recycling centers when describing a paper cup waste disposal chain.

Role of Humans

Students rarely mentioned humans in their supply and waste disposal chains, which is important if students are to understand how humans engineer supply and waste disposal chains to meet their needs. While overall, 22.4% of all students mentioned butcher in the hamburger supply chain, this code included when students mentioned "butcher" or "butcher shop/place." When disaggregated, only 13.3% of all students mentioned "butcher," and it is questionable as to whether the students meant butcher as a person or place. Of all responses mentioned, only 9.8% of all students mentioned humans (excluding those coded as "butcher") as part of their hamburger supply chain. Of those who mentioned humans, they most often used ambiguous pronouns or "people" (6.1% of all students). For example, one student wrote:

> *They* probably were cutting it off the animals [italics added]

Another stated:

> in the factory where the *people* made the hamburger [italics added]

as step in the supply chain. Students rarely mentioned the people involved in the transportation process, processing of the meat, or caring for the cows, even though humans interact with the hamburger at each step of the supply chain.

Similarly, students rarely mentioned humans at any stage of the waste disposal chain when tracing either the trash or recycling waste disposal chain. 17.3% of all students included humans in some manner when tracing the paper cup waste disposal chain. Student references to humans tended to be vague; 5.3% of all students referred to humans through the use of pronouns or "people". For example, one student wrote:

> They remake the cup

Another student stated:

> They bury the cup underground.

When students mentioned a specific group of people, it generally related to the person who transports the cup, such as the "garbage man" or recycling person. The fact that students rarely mentioned humans in their supply and waste disposal chains may be due to limitations of the questions. The supply chain question asked students to trace the supply chain, including "where is it?" and "what is it?" The waste disposal chains asked students to trace the waste disposal chain, including "what was it?" and "where did it come from?" Neither question specifically asked students to include the people involved in the chain, although it is important to note that some students did. On the other hand, students may not have mentioned humans because they may not recognize how humans are connected to, and dependent on, natural systems.

Shephardson and his colleague's (2007) found that students most often conceive of the environment as a place where animals and plants live. They state, "This mental model separates humans from the environment. In other words, environments are natural places and humans do not live in, rely on, or impact the environment" (p. 340). Regardless of why the students did or did not include humans as part of their supply and waste disposal chains, it is important that students learn about the role that humans play in their science classes so that they become a prominent part of their environmental literacy, where they will automatically include humans interactions in supply and waste disposal chains without being specifically asked to include them. We argue that it should be a part of their science/environmental discourse.

Infrastructure

In order for students to learn more about how supply and waste disposal chains are connected to natural systems, they need to learn the actors and locations/places involved and how these actors and locations/places are connected to each other: the infrastructure. In both the hamburger supply chain and paper cup waste disposal chain, students focused on actors and places, but these chains require infrastructure that connects the various actors and locations. Students mentioned transportation much less often than they mentioned locations or places when depicting supply and waste disposal chains. In the hamburger supply chain, only 26.5% of all students mentioned some form of transportation. One elementary school student who included transportation wrote the following as the hamburger supply chain:

> The hamburger factory delivery truck.
> [Before that] The hamburger factory.
> [Before that] The processing mill.
> [Before that] Beef in production plant.
> [Before that] The farm show.
> [Before that] A full grown cow.
> [Before that] a calf from a cow.

While this student mainly mentioned actors or places, he/she did also mention a factory delivery truck, which implied the transportation of the hamburger meat. In the paper cup waste disposal chain 58.5% of student who traced the trash waste disposal chain and 33.3% of student who traced the recycling waste disposal chain mentioned transportation. Similar to the results of Calabrese Barton et al.'s (2005) study of children's understanding of food systems, the students in our study only discussed moving products between locations (e.g., from the farm to the factory), not within locations (e.g., within a factory), which is exemplified by the student response above.

While some students did mention transportation, it is important to build on student's initial understanding to help them develop sophisticated understanding of transportation infrastructure that includes between and within locations. This is particularly important when considering issues such as carbon footprints of food and merchandise production.

Transformation of Matter and Energy

In the hamburger supply chain and paper cup waste disposal chain, students focused on tracing matter through various actors and locations, but rarely mentioned some type of transformation of matter. Students rarely recognized the role of energy consumption in supply chains and waste disposal chains. The dish washing question asked students to list resources used when handwashing and using a dishwasher to wash dishes. Students most often mentioned matter as resources, but rarely mentioned energy. They listed familiar resources such as soap and water (Table 3). When they did mention energy, they more often mentioned it as a resource used by a dishwasher (39.1%) to wash dishes, but rarely mentioned it as a resource used when handwashing dishes (2.2%). This suggests that students may not recognize that electricity is used to heat water (which occurs in both handwashing and using a dishwasher), not just to "run" a dishwasher.

Table 3. Percentage of elementary, middle and high school students who mention resources used when handwashing or using a dishwasher to wash dishes

Resource	Total (percentage)	
	HW (n=412)	DW (n=412)
Soap	79.1	67.0
Water	75.0	60.4
Sponge	25.2	1.2
Towel	35.9	2.9
Electricity	2.2	39.1

*HW = handwashing, DW = dishwasher

Student descriptions of how matter was transformed in supply and waste disposal chains were vague. This supports the findings of Calabrese Barton and her colleagues (2005) that what happens to food between the farm and the store is a 'black box'. Factories were places where food transformations simply happened; students did not really know what type of transformations occurred. In our study, in the hamburger supply chain question students most often mentioned transformation of matter at a factory, where the cow meat was cut up or simply stated that the meat was "processed." When asked how hamburger meat and a cornfield could be connected, students most often stated that there could be a connection because cows eat corn (29.1%), while only a small percentage of all students gave more detailed responses explaining *why* cows eat corn (2.2%). For the trash waste disposal chain, 30.5% of all students stated that the paper cup would decompose. When tracing the recycling waste disposal chain, 26.5% of all students mentioned that the cup was processed and 48.3% of students stated that the cup was made into a new product. But again, they were vague – they simply stated that the cup was "processed" or "made into new product" (Figure 4). When asked how a paper cup and a tree could be connected, most students stated that a paper cup is made from a tree (73.3%), while 4.9% of all students mentioned some type of process that the tree undergoes to be made into paper (see examples on p. 11-128).

Human Actions and Environmental Impact

The previous section discussed findings regarding student understanding of the connections between human engineered and natural systems. This section addresses student understanding of the impact of human actions on environmental systems. In the hamburger supply chain, most of the negative impact on the environment comes from feedlots, where cattle consume large amounts of corn and where large amounts of waste are produced. While many students may not be familiar with large, industrial-scale beef production in the United States, large-scale beef production produces much of the beef in this country and has a larger impact on the natural environment than small, rural farms (Pollan, 2002; United States Office of Wastewater Enforcement Environmental Protection and Compliance Agency, 1993; Ward & Schroeder, 2002; Woiwode &

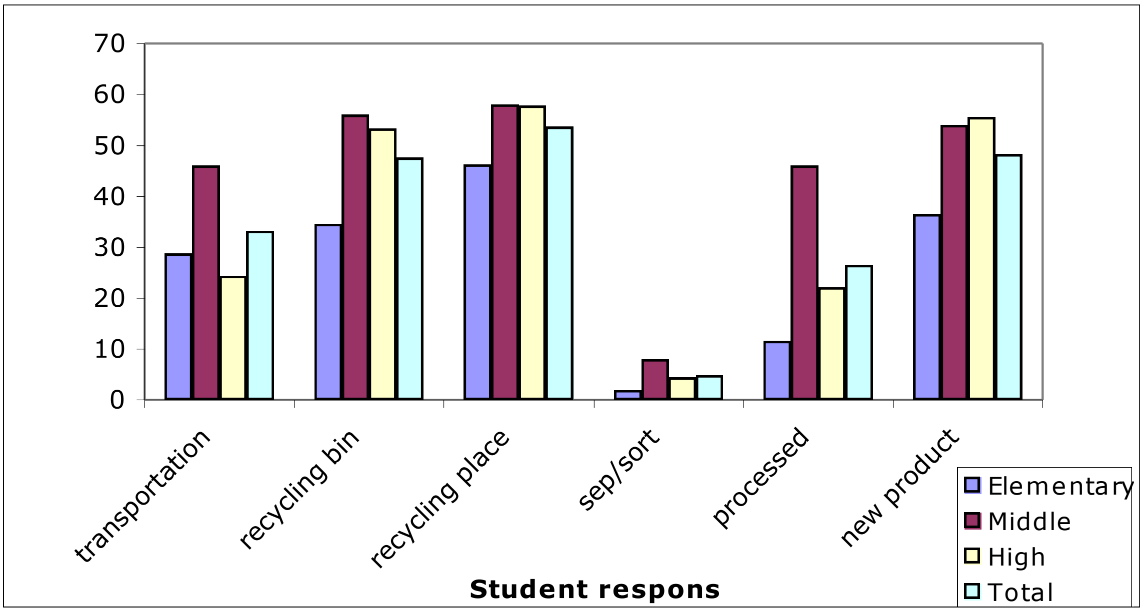

Figure 4. Percentage of elementary, middle, and high school students who mentioned steps of paper cup recycling waste disposal chain

Henning, 2005) Therefore, it is significant that students do not mention feedlots in their hamburger supply chain, as feedlots have a large impact on the natural environment.

The steps of supply and waste disposal chains that have the greatest environmental impact may be "invisible" or a "black box" to students. In the case of the hamburger supply chain, feedlots were invisible. In the paper cup waste disposal chain, students didn't seem to have a good understanding of how landfills work (that the paper cup would not decompose back into soil) or what happens at recycling centers (they know that the cup gets turned into a new product). It is understandable that students may not know what goes on at landfills and recycling centers. They may not have any experiences with either; they may not have learned about them inside or outside of school. Since students do not understand the processes that occur in these locations/places (i.e., how the matter is transformed), they cannot understand the impact that these processes have on the natural environment.

The dish washing question also has interesting implications for connections between human activities and environmental systems. First, students must recognize that they use resources from the environment in everyday activities. Second, students must be aware of how the resources that we use are connected to the environment via supply and waste disposal chains and the impact that using these resources have. When asked what impact using these resources has on the environment, students often responded "no impact," or "don't know"; they demonstrated limited knowledge of the impact that using various resources has on the environment. For example, when students did recognize some impact using water has on the environment when using a dishwasher, they often stated that there would be "less water" (30.9%). Students less often mentioned the impact in terms of waste disposal chains and the resulting by-product – that the water would be dirty or polluted (6.4%) or that the water could pollute or harm something else (2.4%). When students mentioned energy as a resource consumed when using a dishwasher, students also most often stated that there would be “less” energy (21.2%). Only 8.7% of students mentioned that energy use causes pollution, a by-product of its use.[4]

While students more often link the impact of water and electricity use to the supply chain, students tied the impact of using soap to the waste disposal chain. Students stated that the soap could pollute water, or harm animals and plants (22.1% when handwashing, 22.8% when using a dishwasher). These students recognize that a by-product of using soap may be harmful to the environment, such as animals and plants. This is an important recognition, as one way to view impact on environment is in terms of the by-products that the dishwashing process creates. This question suggests that students need to be able to understand supply and waste disposal chains (where resources and services come from and end up) in order to understand the impact that human actions have on the natural environment.

In addition, students need to be able to connect environmental issues such as global warming to the *source* (i.e., fossil fuels) and the *process* (burning of the fossil fuels that releases carbon dioxide) that contributes to global warming. When students were asked what they thought causes global warming/global climate change, the most common causes students gave were fossil fuels (19.6%), pollution (20.8%), and cars (14.7%) (Table 5). Student responses were coded as “pollution” if they wrote “pollution”, but did not state the source of pollution or specify the type of pollution. For example, one student wrote:

> Pollution in the air gets into the atmosphere and adds extra insulation to the earth, making it warmer.

While some students recognized that fossil fuels and cars were causes of global warming, many held misconceptions. 12.8% of students said that sun causes global warming, 10.7% mentioned the weather, and 6.4% said the Earth’s rotation were causes of global warming. The IPCC has found that humans are the main cause of climate change (2007). Thus, it is important for students to recognize the causes of climate change; they must understand how human actions have impacted the environment in a negative manner, resulting in climate change.

Learning Progression

In general, high school students have a more developed understanding and awareness of supply and waste disposal chains and major environmental issues. The number of steps mentioned in supply chain is significantly associated to school level (elementary, middle, and high) ($\chi^2(4, N = 412) = 38.542, p < .001$), as is the number of steps mentioned in the trash waste disposal chain ($\chi^2(4, N = 248) = 15.206, p < .005$). High school students mentioned the most steps and elementary school students mentioned the fewest steps. Also, high school students mentioned more steps in the recycling disposal chain than middle or elementary school students.[5] Furthermore, in general, high school students mentioned connections to the natural system (e.g., cow, farm, growth, plants) more often than middle or elementary school students. 9.1% of all high school students mentioned “plants” when describing the hamburger supply chain while only 3.2% of elementary and 2.9% of middle school students mentioned them. When asked about connections between hamburger meat and a cornfield and a paper cup and a tree, high school students more often mentioned provided details (e.g., were more likely to trace matter) about how they were connected than elementary or middle school students.

Table 4. Percentage of student responses to awareness of global warming

	Grade level (percentage)			Context (percentage)			
Response	Elementary (n=125)	Middle (n=140)	High (n=147)	Rural (n=121)	Suburban (n=146)	Urban (n=412)	Total (n=412)
Yes	68.8	73.6	94.2	75.2	93.2	69.0	79.4
No	26.4	17.9	3.2	19.8	2.1	24.8	15.3
No Response	4.8	8.6	2.6	5.0	4.8	6.2	5.3

There were no clear trends for resources listed or impact on the environment amongst students according to grade level in the dishwashing question. In the global warming question, 68.8% of elementary, 73.6% of middle, and 94.2% of high school students responded that they have heard of global warming; there was a significant association between student responses and grade level ($p < 0.05$) (Table 4). Of those who have heard of global warming, more high school than elementary school students mentioned reducing fossil fuels as a way to reduce global warming even though 22.1% of elementary and 26.8% of high school students mentioned fossil fuels as a cause of global warming (Tables 5 and 6). This suggests that older students are more aware of cause and effect relationships. In this case, reducing fossil fuel emissions (a major cause of global warming) could help reduce global warming.

Table 5. Percentage of student responses for cause of global warming

Response	Level (percentage)			Context (percentage)			Total
	Elementary n=86	Middle n=103	High n=138	Rural n=91	Suburban n=136	Urban n=100	n=327
Fossil fuels	22.1	7.8	26.8	12.1	32.4	9.0	19.6
Deforestation	4.7	0.0	2.2	2.2	2.2	2.0	2.1
Aerosols	4.7	5.8	7.2	14.3	3.7	2.0	6.1
Ozone	2.3	19.4	18.8	20.9	16.2	7.0	14.7
Sun	9.3	14.6	13.8	16.5	12.5	10.0	12.8
Pollution	5.8	26.2	26.1	22.0	20.6	20.0	20.8
Cars	14.0	16.5	13.8	11.0	19.1	12.0	14.7
Weather	14.0	14.6	5.8	12.1	5.1	17.0	10.7
Earth's rotation	9.3	6.8	4.3	5.5	2.9	12.0	6.4
Industry	10.5	9.7	8.0	6.6	12.5	7.0	9.2
Don't know	8.1	2.9	5.8	5.5	3.7	8.0	5.5

*Answers not included in table were coded as no response, other (not enough similar answers to constitute a category), or unintelligible.

**Responses were coded as "cars" when they specifically mentioned that cars or pollution from cars causes global warming. If a student stated that global warming is caused by carbon dioxide from cars, the response was coded as both "cars" and "fossil fuels."

Table 6. Percentage of student responses for ways to reduce global warming

Response	Level			Context			Total
	Elementary n=86	Middle n=103	High n=138	Rural n=91	Suburban n=136	Urban n=100	n=327
Reduce fossil fuels	7.0	1.9	14.5	8.8	12.5	3.0	8.6
Reduce deforestation	2.3	1.0	5.1	5.5	2.2	2.0	3.1
Plant trees	0.0	1.0	4.3	1.1	3.7	1.0	2.1
Stop use of aerosols	1.2	7.8	4.3	11.0	2.9	1.0	4.6
Reduce pollution	3.5	22.3	18.1	14.3	16.2	16.0	15.6
Drive less	15.1	23.3	27.5	19.8	31.6	14.0	22.9
Alternative energy	12.8	10.7	9.4	6.6	19.1	3.0	10.7
Can't be reduced	8.1	3.9	4.3	5.5	2.9	8.0	5.2
Don't know	16.3	7.8	4.3	8.8	9.6	7.0	8.6

*Answers not included in table were coded as no response, other (not enough similar answers to constitute a category), or unintelligible

Context

Overall, there were some trends in student answers across context. For the hamburger supply chain, rural students seemed to have more developed ideas about the chain. Rural students more often made connections between the human engineered hamburger supply chain to natural systems more; rural students mentioned parents and growth significantly more often than suburban and urban students ($p < 0.05$). Rural students also mentioned more steps in their supply chains than urban and suburban students ($\chi^2(4, N = 412) = 9.945, p < .05$). Interestingly, 16.43% of urban students mentioned "animal" or some type of animal other than a cow, while rural and suburban students more often specifically mentioned "cow" in their supply chains. There was no significant difference between the percentage of students who mentioned humans in their supply chain according to context.

In the paper cup waste disposal chain question, a significantly higher proportion of suburban than urban students mentioned that they would recycle the paper cup ($p < 0.005$), but there was no significant difference when comparing rural to suburban or rural to urban.

When asked about a connection between hamburger meat and a cornfield, more suburban (70.5%) than rural (67.8%) than urban students (53.1%) thought that there could be a connection. In the dishwashing question, suburban student responses more frequently related to supply and waste disposal chains than rural or urban students. Interestingly, urban students mentioned "junkyard" more often than rural and suburban students, and "landfill" least often. This could suggest that urban students have a less developed understanding of the trash waste disposal process – they may confuse the difference between a junkyard and landfill. On the other hand, they may understand what a junkyard is and have experiences with objects such as paper cups ending up at junkyard.

There were also slight trends in student knowledge of global warming in different contexts. For example, a higher percentage of suburban students (93.2%) than rural (75.2%) and urban students (69.0%) have heard of global warming, which was significant ($p < 0.05$). Suburban students gave “fossil fuels” as a cause significantly more often than rural or urban students ($p < 0.05$). Rural students and suburban students mentioned a depletion in the ozone layer (coded as “ozone”), significantly more often than urban students ($p < 0.05$). Rural students more often mentioned “aerosols” such as aerosol spray cans or hair spray cans significantly more often than suburban students ($p < 0.05$) and more often than urban students.[6] Rural and urban students more often mentioned weather as a cause of global warming than suburban students ($p<0.05$). For example, one student stated a cause of global warming is, “when warm air and cool air mix,” another wrote, “a front of a tornado, hurricene, funel, weripool [sic].” Many of the student responses coded as “weather” confused weather as a cause, rather than a result, of global warming. Overall, it appears that suburban students may have a slightly better understanding of the causes of global warming than rural or urban students, but students across contexts held incorrect ideas about global warming. Overall, results from this study suggests that context may play a role in student understanding of how human connections and interactions with environmental systems.

Summary

Overall results indicate that students’ scientific accounts across grade level and context are incomplete (practice 2). In both supply and waste disposal chains, students mentioned energy, infrastructure, and by-products less often than locations/places. Similar to Calabrese Barton and her colleague’s (2005) study, these locations/places seemed to present a ‘black box’; students did not often mention processes that occurred at the locations/places. In the paper cup question, students often stated that they would recycle the paper cup, even though we do not currently have the facilities available to recycle them. Students also mentioned that the paper cup would decompose and return to the soil in a landfill even though the structure of landfills does not allow for paper cups to decompose and return to the soil. Similar to Kempton’s (1997) and Taber and Taylor (2009) findings, we found that students also held incorrect or incomplete knowledge about the causes of global warming. They often stated the ozone, aerosols, or sun causes global warming.

Conclusion

Implications for Science Curriculum and Teaching

We are increasingly faced with environmental issues that are caused by human impact on the environment. In order to alleviate some of this impact, we need to better understand how humans are connected to, or intertwined with, natural systems. This exploratory study is a starting point for understanding what students know about some of these connections. We aim to teach students to be environmentally literate, where students understand connections between human engineered and natural systems and are able to think in an interdisciplinary way, as environmental issues cross traditional disciplinary boundaries. We argue that students must be able to participate in three practices: inquiry, scientific accounts, and citizenship. In this article, we focused on the second two practices: scientific accounts and citizenship. Students must be able to use scientific accounts to explain what is going on, such as what the processes and actors involved in supply and waste disposal chains or global warming. They must then be able to use their understanding of the accounts to make informed decisions.

With regards to the second practice, scientific accounts, it is essential for students to understand the structure of systems and the constraints on these systems. In particular, students need to understand the structure of macroscopic and large-scale systems (i.e., food, water, waste disposal, etc.), which includes the connections between human engineered and natural systems and the impact that human actions have on natural systems. The first step may be in teaching students where natural and human engineered systems connect at the beginning of supply chains (e.g., hamburger meat comes from cows, paper cups are made from trees, plastic bags are made from petroleum). On the other end, services and products we use eventually reenter the natural environment (e.g., our use of fossil fuels results in carbon dioxide entering the atmosphere). Students also need to know the various *actors and places* involved in systems such as supply and waste disposal chains. For example, in the mass production of hamburgers, an important step in the supply chain is feedlots. It is important to students to be familiar with feedlots because they create much waste (by-products) that enters into the environment and can have severe negative consequences such as polluting water supplies. In addition, they need to learn how *humans* interact and alter supply and waste disposal chains. In supply and waste disposal chains, students need to be aware of not only the actors and places, but they must be able to trace matter and energy through these systems, recognizing how matter and energy are transformed, and how the transformation may be constrained within systems. For example, in a landfill, decomposition of matter is constrained by the structure of landfills (i.e., compacting of waste to remove oxygen), and the conservation of matter and energy. In the dishwashing question, students must be aware of the resources used, such as water, energy, and soap, how these resources come to us. Students need to understand how human and natural systems are connected and how infrastructure connects these systems at each step of systems. In addition, as already mentioned in the discussion of feed lots, students must know how various by-products are created at each step and some of these by products can contribute to environmental problems such as global warming.

Student understanding of scientific accounts and the application of scientific accounts has implications for the use of scientific reasoning for responsible citizenship, the third practice. When students have incomplete understanding of supply and waste disposal chains, they can not make informed decisions. For example, if students do not know where they food comes from or where their waste goes, they cannot make informed decisions about their actions. Students' inaccurate or incomplete understanding of the causes of global warming (the sources and supply and waste disposal chains, their infrastructure and by-products that contribute to it) lead to inaccurate or incomplete understanding of how humans can act as citizens to help reduce global warming. Many students held incorrect ideas about the causes of global warming (i.e., aerosols, ozone, sun, weather) or have a general understanding that pollution causes global warming, but do not specifically state the source or type of by-product. 12.8% of all students mentioned the "sun" and 10.7% mentioned that the weather and/or the earth's rotation cause global warming, which along with being misconceptions, fails to recognize the role that humans play in global warming. Taber and Taylor (2009) similarly found that students confused issues with holes in the ozone layer and global warming. Kempton (1997) asserts that the cultural models, conceptual models shared by most of the people in a culture of the fundamental ways the world works, about causes of global warming are often incorrect or irrelevant to the problem. The mismatch between cultural models and reality have serious consequences for our efforts to solve problems. Thus, even when one desires to make good decisions as to how to interact with their environment or solve environmental problems, if they do not have a correct understanding of the science, they may use inappropriate models in their decision-making.

Science curriculum needs to do a better job of teaching students about how humans are part of the environment. One way to do this would be to include more curricula that allows students to study connections between human engineered and natural systems. This could help teach students how to reason about "causal relationships". This is essential, as the NEETF/Roper report (2005) states, “This understanding of causal connection is the single biggest problem in the environmental knowledge gap” (p. 14).

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Notes

[1] The full assessment is available at http://edr1.educ.msu.edu/EnvironmentalLit/index.htm.
2 Each student response coded, such as “transportation” or “factory” represented a step, or aspect of the supply chain or waste disposal chain that students recognized.
3 While students did not mention waste reentering a natural system, the waste and by-products from the recycling process does reenter natural systems.
4 Due to space limitations, the data for this question cannot be fully explored in this paper. More information can be found in Tsurusaki, B. K., & Anderson, C. W. (2007). Students’ understanding of connections between human engineered and natural environmental systems: Similarities and differences across grade level and context. Paper presentation, National Association for Research in Science Teaching, New Orleans, LA.
5. A chi square test of association could not be run because no elementary school mentioned 5 to 6 steps.
6. Test of significanCE could not be run because the urban sample did not satisfy the standard binomial requirement that n(p) and n(1—p) must both be equal to or greater than 5.

Appendix A

Participants

Grade	**Subject**	**Context**	**Number of Assessments Analyzed**	**Number of Assessments Collected**
4th	Science	Rural	34	34
5th	Science	Suburban	46	46
4th	Science	Urban	30	30
5th	Science	Urban	15	15
6th	Science	Rural	40	40
6th	Earth Science	Suburban	25	86
7th	Life Science	Suburban	25	95
6th	Science	Urban	25	75
6th	Science	Urban	25	75
9th	Earth Science	Rural	10	10
10th	Biology	Rural	18	18

11th	Chemistry	Rural	19	19
9th	Physical Science	Suburban	25	41
9th	Biology	Suburban	25	59
10th	Biology	Urban	25	39
11-12th	Global Science	Urban	25	41

*The goal was to analyze 50 assessments per level (elementary, middle, high school) per context (rural, suburban, urban). When there were 50 assessments per level and context or less, the entire set of assessments was analyzed. When there were more than 50 assessments per level and context, a random sample was taken.

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Öğrencilerin insan yapımı ve doğal çevresel sistemler arasındaki bağlantıları anlamaları

Bu çalışma iki alandaki gelişmelere dikkat çekmektedir: (1) Bilim öğrenme üzerine yapılan araştırmalar ve bu araştırmaların politika ve pratiğe uygulandığı *öğrenmenin gelişimi* ve (2) bağlı insan ve doğal sistemler üzerine *disiplinler arası* çalışmaların önem kazandığı doğa bilimlerindeki ilerlemeler. Çalışma, yeryüzünün doğal sistemlerinde başlayıp ve biten esas mal ve hizmetleri (yiyecek, su, ulaşım) tedarik eden insan sistemleri üzerine yoğunlaşmaktadır. Öğrencilerin insan eylemlerinin çevresel sistemleri nasıl etkilediği hakkında ne bildiklerini araştırmak için arz ve çöp işleme zincirleri üzerine yoğunlaşan değerlendirmeler geliştirdik. Ayrıca, çok önemli bir çevre meselesi (küresel ısınma) ile ilgili görüşleri soruldu. Değerlendirmeler, kırsal, varoş ve şehir okullarındaki ilk, orta ve liste öğrencilerine uygulandır. Bu çalışmadan elde edilen sonuçlar öğrencilerin insan ürünü ve tabi sistemler arasındaki ilişkiyi farklı sınıf düzeylerinde ve bağlamda nasıl kurduklarına yönelik bir fikir vermiştir. Bu da eğer çevresine karşı duyarlı ve sorumluluğu öğrencilerimize öğreteceksek çok esaslı bir meseledir.