Connecting Personal Actions to Environmental Systems

Blakely K. Tsurusaki and Charles W. Anderson
Michigan State University
tsurusak@msu.edu

Paper presented at the annual meeting of the National Association for Research in Science Teaching, San Francisco, April 3-6, 2006

This research is supported in part by three grants from the National Science Foundation: Developing a research-based learning progression for the role of carbon in environmental systems (REC 0529636), the Center for Curriculum Materials in Science (ESI-0227557) and Long-term Ecological Research in Row-crop Agriculture (DEB 0423627. Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

Abstract

The human systems that supply all of our essential goods and services - food, clothing, shelter, water, transportation - 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*. We developed opened-ended questions asking students to trace products as far as they could back towards the product's origins, or forward as far as they could for waste that they throw away. We focused on two supply and waste disposal chains: the supply chain for a hamburger and waste disposal chains for a paper cup. In addition, students were asked about the resources used when washing dishes and the impact that using these various resources have on the environment. This question indirectly asked students to trace the supply chains or waste disposal chains of various resources used when washing dishes. The final question analyzed asked students about global warming in order to ascertain how aware students are of a major environmental issue and what they know about it. Results from this study highlight key fundamental principles regarding the structure of macroscopic systems (goods and services such as food supply chains), connections between human-engineered and natural systems, and constraints on systems (i.e., tracing matter and energy) that are critical if students are to understand the role that humans play in environmental issues and make responsible decisions as citizens and stewards of our environment.

Introduction

The Role of Environmental Science Literacy in Schools

National science education reform documents (National Research Council, 1996; American Association for the Advancement of Science, 1990), argue that science is essential

because people use scientific information to make choices in their everyday lives and they need to be able to engage in public discourse about issues that involve science and affect society. These reform documents emphasize the need for all students to be scientifically literate, which is defined as being able to understand and apply basic scientific ideas and processes. While science education is imperative, Eisenhart, Finkel and Marion (see, 1996for more information) assert that U.S. schools are asked to overcome four problems in science education: the public's low level of scientific knowledge, poorly taught science, low levels of women and minorities in science fields, and inadequate preparation to use scientific knowledge in every day decision making. "Taken together, these problems are said to diminish the country's ability to compete effectively in the global economy and to address serious social and environmental issues" (Eisenhart, Finkel, & Marion, 1996, p. 262). They argue that national reform documents focus on content, but "no clear conceptual connections, strategies to achieve, or empirical support are offered to suggest how knowledge of science content and methods might lead to its use in socially responsible ways; the link is merely assumed" (Eisenhart, et al., 1996, p. 269). We believe that environmental science literacy, which focuses on interdisciplinary science that studies coupled human and natural systems, provides a conceptual framework for teaching students science in ways that recognize how they encounter science in their everyday actions and how their actions impact the environment. It focuses on the capacity to understand and participate in evidence-based discussions of the effects of human actions on environmental systems. Thus, environmental science literacy is fundamental to students' participation as informed citizens in a society that must address increasing environmental issues.

Environmental Science Literacy: Interdisciplinary Understanding

United States citizens live in and impact their environment, but the majority of them 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. The science of ecology can and should play a greatly expanded role in ensuring a future in which natural systems and the humans they include coexist on a more sustainable planet" (Environmental Visions Committee, 2004, p. 2). The ESA argues that the public must be educated so that ecological knowledge informs individual choices about sustainability. The public will need 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., fuel emission testing, recycling). Modern ecology now focuses on *linked human and natural systems* (see, for example, AC-ERE, 2003). Therefore, science should be taught in an ecological manner that integrates the traditional science disciplines and connects them as they are connected in the natural world.

The integration of science disciplines is increasingly 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 climate change. 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…[and] 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, 2001; 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 and how disciplines are intertwined.

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. While 89% of Americans "strongly or mostly agree that the condition of the environment will play an increasingly important role in the nation's economic future" (The National Environmental Education & Training Foundation (NEETF), 2000) and environmental education is becoming increasingly important to society (Environmental Visions Committee, 2004; Kempton, Boster, & Hartley, 1995), there are many gaps in our understanding of how students reason about environmental issues. Kempton et al.'s (1995) study 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.

Connecting human actions with 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 - food, clothing, shelter, water, transportation - begin and end in the earth's natural systems. There is little research about what students know about how human actions affect 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) and Calabrese Barton et al. (2005) reported on a qualitative study of what high poverty urban children understand and believe about food and food systems. But more research is needed about what students know about how *human actions affect environmental systems*; this research focuses on connecting human actions to environmental systems. An assessment was developed based on our own teaching and research experiences and best guesses as to what would elicit interesting information about student knowledge. The Connecting Personal Actions to Environmental Systems assessment focuses on supply and waste disposal chains and the connection between human engineered and natural systems. In particular, we were interested in the following questions:

- How aware are students of food supply chains and waste disposal chains?

- How aware are students of connections between goods and services that involve transfer of matter and energy? (i.e. corn and hamburger or a tree and a paper cup)
- 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?

It is essential to understand what students do and do not know about these connections in order to teach them to be environmentally literate. The ultimate goal of this work is to help students develop model-based reasoning about supply and waste disposal chains, which requires that students be able to trace matter through these chains and make connections between them (see Anderson et al., January, 2006 for more information). Through understanding supply and waste disposal chains, students can begin to examine human ecological footprints, how they can have a greater or lesser impact on the environment based on decisions that they make with regards to supply and waste disposal chains, and realize that individual and societal decisions make a difference on our natural environmental.

Data Sources

Assessment Questions

Because little previous research is available regarding students' knowledge of how human actions are connected to environmental systems, the test items were based on the experiences of members of the working group and our best guesses about questions that might produce interesting responses. We developed opened-ended questions, with some questions given in the form of tables, 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 (see Appendix A for an example). 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? 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.

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 or waste disposal chains of various resources used when washing dishes.

The final question analyzed consisted of three parts. 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.

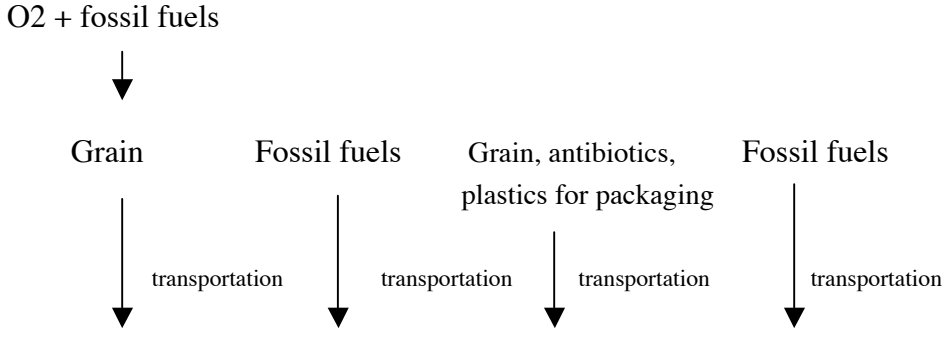
Participants

Three high school teachers, one sixth grade middle school teacher and one fourth grade elementary school teacher, all teaching in rural areas, administered the assessment. Data from 44 ninth and tenth grade biology, physical science, and earth science high school students, 26 sixth grade middle school students, and 34 fourth grade elementary school students were analyzed.

Data Analysis

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 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.



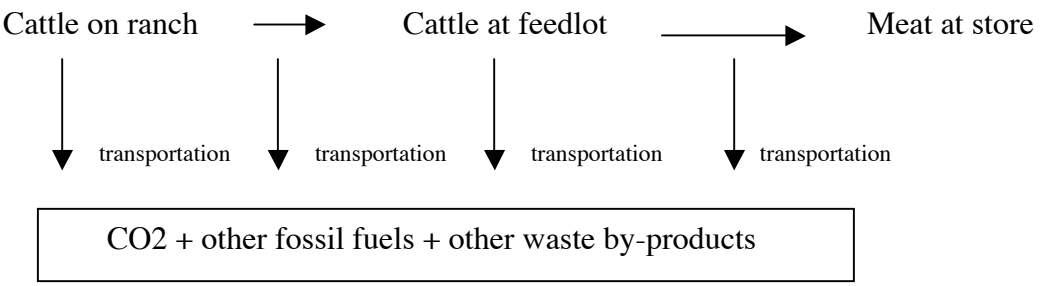


Figure 1. Simple diagram of a hamburger supply chain.

In short, 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 produced by the systems. 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.

Procedures

The assessment included a combination of multiple choice and open response items. Analysis was guided by a Working Paper, written by the lead author of the paper, with contains rubrics for coding student responses (Tsurusaki, 2006). Emergent codes were developed from analyzing a sample of assessments. These codes were then used to developed rubrics, which 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 (from less developed understanding to greater understanding).

Reliability of the rubrics was assessed by having a second coder independently code a sample of the assessments. When there were discrepancies, the rubrics were revised until at least 90% reliability was achieved. For all questions, frequency counts were obtained and student response percentages calculated overall and separately for elementary, middle, and high school students. Analysis procedures for specific questions are explained in the *Results* section.

Results

Each section of the results will contain four parts: 1) Question, 2) Data analysis procedures, 3) Data results, and 4) Discussion. Most results are represented by figures. Exact values of figures are presented in the Appendices B-F.

Tracing steps in the hamburger supply chain

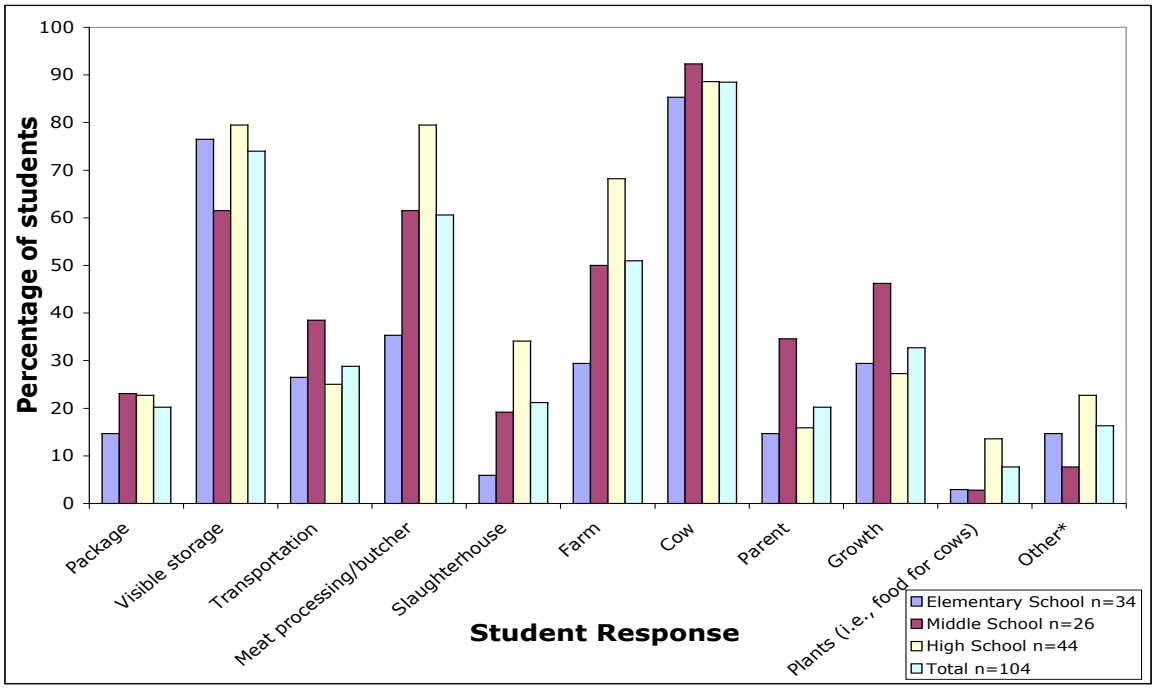
Hamburger supply chain question

This question asked students: You go through the lunch line at school and see that they are serving hamburgers. Where did the hamburgers come from? The students were asked to trace the supply chain of the beef back as far as they could.

Data Analysis Procedures

In this question, we were only interested in whether students mentioned a particular step, such as *cow*. Thus, student responses were weighted so that if they mentioned *cow* more than once in the supply chain, it was only coded once. Frequencies of responses were tabulated and percentages of students per elementary, middle, and high school, and overall were calculated. In addition, the total number of steps 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). For the hamburger supply chain, students mentioned between 0 and 7 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 = 6-7 steps.

Results



**Responses were coded as other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*
***No mention of feedlots*

Figure 2. Percentage of students who mentioned steps of hamburger supply chain

Students most often mentioned *visible storage* such as a freezer or store (74%), some type of *meat processing* or place where meat is processed or cut up such as at a butcher or factory (60.6%), *farm* (51.0%), and *cow* (88.5%) when tracing the hamburger's supply chain. It is noticeable that no students mentioned feedlots as part of the hamburger supply chain even though they a play major role in the mass production of beef, and only 21.2% of the students mentioned *slaughterhouses* and 7.7% of the students trace the hamburger supply chain back to *plants* or food for cows. In addition, the number of steps that students mentioned in the supply chain increased across school level. Elementary school students most commonly mentioned three different steps in the hamburger supply chain, while most middle and high school students most often mentioned four steps (Figure 3). There is a statistically significant association between the number of steps mentioned by students and school level ($\chi^2(4, N = 104) = 25.374, p < .0001$).

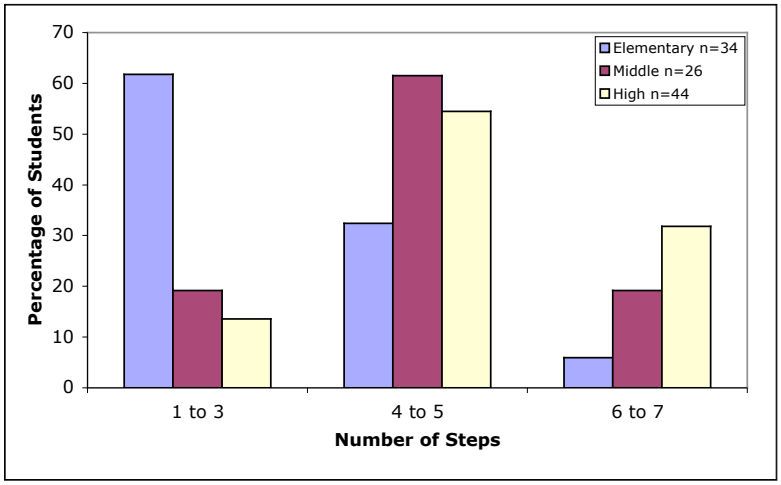


Figure 3. Number of steps in hamburger supply chain mentioned by students

Discussion

From analysis of this question, four key points arise. First, students tended to describe events and locations, rather than trace matter and energy. For example, students most commonly mentioned some type of *visible storage* such as a store or freezer when depicting the hamburger supply chain. Also, out of the ten codes developed from student responses, only two of the codes included some type of processing or transformation of matter - *meat processing/butcher* and *growth*. Second, students' supply chains portrayed stereotypical small-scale, rural hamburger meat production as opposed to large-scale, industrial meat production. Third, few students traced matter across connections from engineered to natural systems. For example, few students traced the hamburger supply chain back to the plants or feed that cows eat. Finally, the number of steps that students mentioned increases across grade level. Thus, perhaps older students recognized that there are more steps involved in the hamburger supply chain than younger students.

Tracing steps in the paper cup waste disposal chain

Paper cup waste disposal chain question

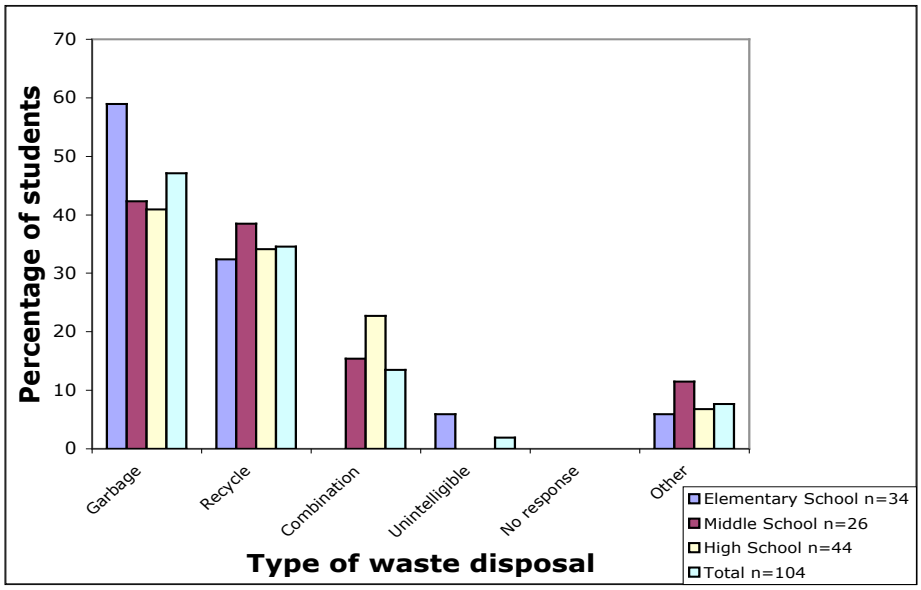
While the previous question asked students to trace the steps of a hamburger supply chain, this question asked students to trace the steps of a waste disposal chain. It contained two parts: Part A, After you finish drinking some water from a paper cup, how would you get rid of the cup?, and Part B, What do you think might happen to this cup once it leaves your hands?

Data Analysis Procedures

For part A, student responses were coded according to the following categories: trash/garbage, recycle, combination (mentioned both recycling and garbage), unintelligible, no response, or other. For Part B, the same data analysis procedure was used for this question as the hamburger supply chain question. We were only interested in whether students mentioned a particular step, thus student responses were weighted so that if they mentioned a step more than once in the waste disposal chain, it was only coded once. In both parts of the question, frequencies of responses were tabulated and percentages of students per elementary, middle, and high school, and overall, were calculated. In addition, in Part B the total number of steps per student were 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). For the paper cup waste disposal chain, students recorded between 0 and 6 steps, which were broken into three groups: low = 0-2, medium = 3-4, and high = 5-6. 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.

Results

For Part A of the question, most students (47.1% of all students) said that they would throw the cup in the garbage. Fewer students stated that they would recycle the paper cup (34.6%) or that they would either throw the cup in the garbage or recycle it (13.5%) (Figure 4). It is interesting to note that students mentioned recycling a paper cup as an option, when in general we lack systems for recycling paper cups.



Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Figure 4. Percentage of students' choice of waste disposal chain

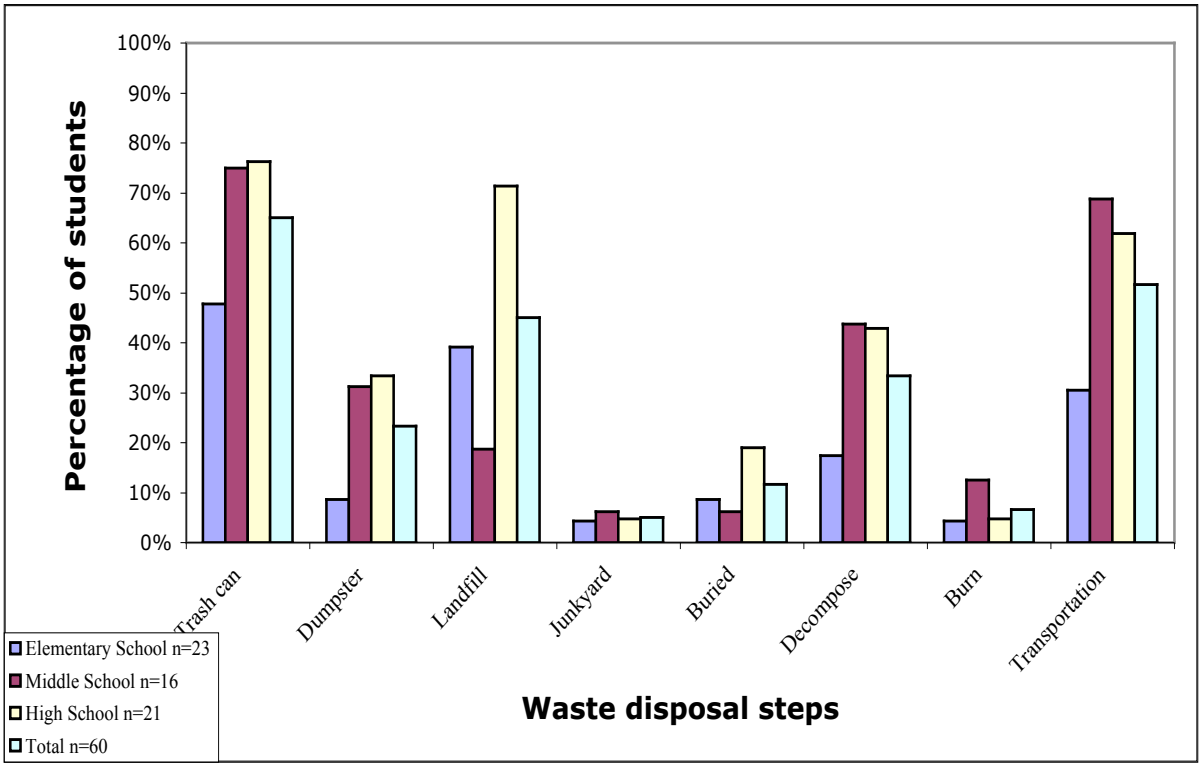


Figure 5. Percentage of students who mentioned steps of paper cup garbage waste disposal chain

Overall, of the students who described the garbage waste disposal chain, students most commonly mentioned *trash can* or garbage can (65.0%), *landfill* or dump (45.0%), and *transportation* or the means by which the cup was moved from one location to another (51.7%). While 51.7% of all students mentioned *transportation*, 61.9% of high school and 68.8% of middle school students included it in their waste disposal chains, but only 30.43% of elementary school students mentioned it.

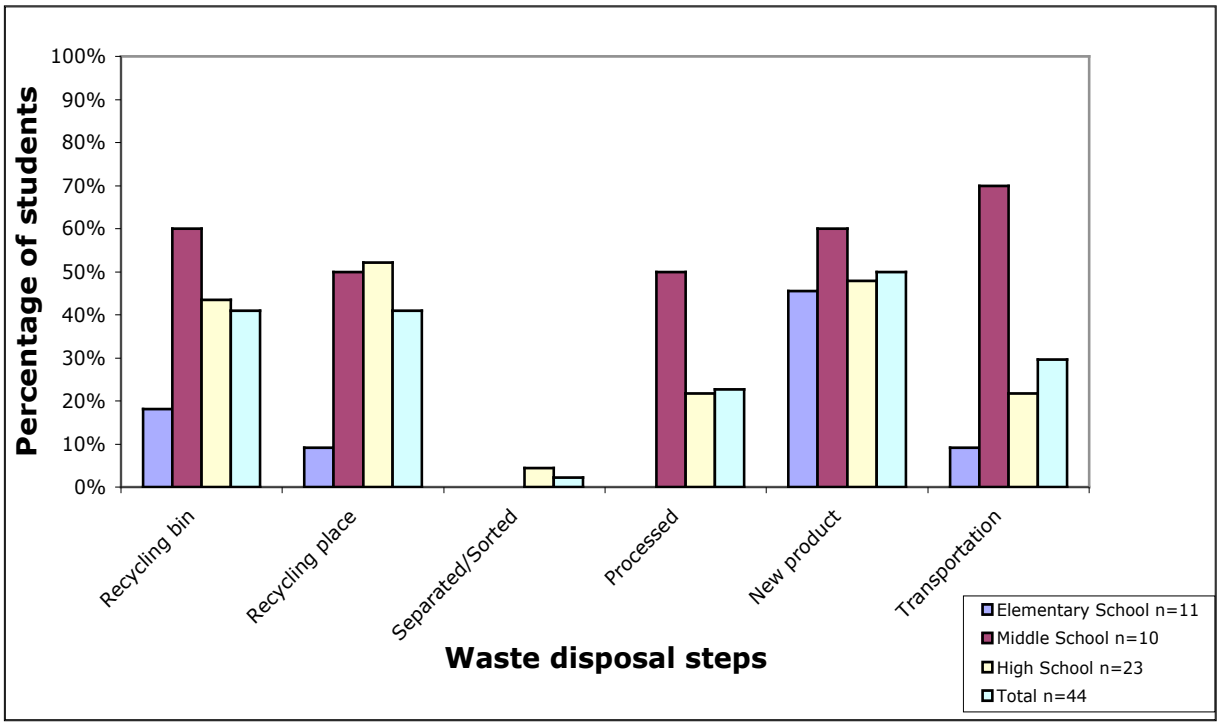


Figure 6. Percentage of students who mentioned steps of paper cup recycling waste disposal chain

Overall, students who described the recycling waste disposal chain most commonly mentioned *recycling bin* (40.9%), *recycling place* or the factory where you take recycling to (40.9%), and that the cup is made into a *new product* (50.0%). A fewer percentage of students, only 2.3% overall, mentioned that the recyclable material must be *separated/sorted* before it can be recycled; all of these were high school students and only represented 4.25% of high school students assessed. Overall, 22.7% of the students mentioned that the cup must be *processed* or go through some type of process before it can be made into a new product. The results show that a higher percentage of students mentioned some type of *processing* in middle school (50.0%) than high school (21.7%), and no elementary school students mentioned *processing*.

In part B, 42.3% of all students, regardless of whether they described the garbage waste disposal chain or the recycling waste disposal chain, mentioned some type of *transportation*, usually a truck, that moves the paper cup from one location or step to another (Figure 5 and

Figure 6). While 51.7% of students who described the garbage waste disposal chain mentioned some type of transportation, a smaller percentage of students (29.6%) mentioned transportation when they described the recycling waste disposal chain.

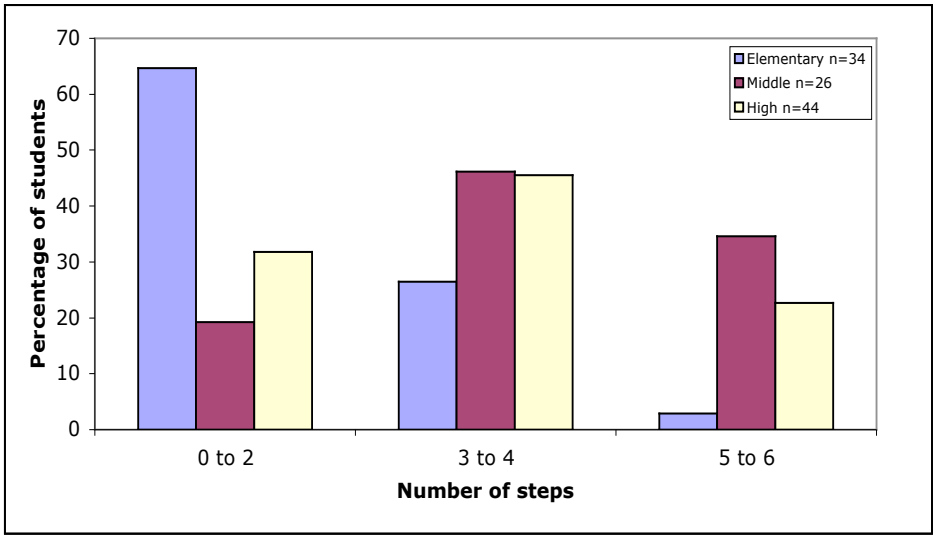


Figure 7. The number of steps in waste disposal chain mentioned by students

Just as we found in student responses to the hamburger supply chain question, middle school and high school students most often mentioned four steps in the waste disposal chain, while elementary school students most often mentioned three steps (Figure 7). There is a statistically significant association between the number of steps mentioned by students and school level ($\chi^2(4, N = 104) = 19.433, p < .01$).

Discussion

Similar to the hamburger supply chain, students tended to describe events and locations, rather than trace matter and energy. In the garbage waste disposal chain, only *decompose* and *burn* include transformation of matter. While *decompose* was mentioned by 33.3% of the students who depicted the garbage waste disposal chain, students more often mentioned *trash can, transportation,* and *landfill*. In the recycling waste disposal chain, students mentioned some

type of *processing* that the paper cup underwent 22.73% of the time but more often mentioned *recycling bin, recycling place,* and *new product*. Much of the recycling waste disposal chain seems to be invisible to students, as they state visible places or things but do not state processes that occur to actually transform the paper cup into a new product. Finally, as in the hamburger supply chain, the number of steps that students mentioned increases across grade level. Thus, perhaps older students recognize that there are more steps involved in the paper cup waste disposal chain than younger students.

Making Connections

Questions

In addition to asking students about a hamburger's supply chain and a paper cup's waste disposal chain, students were asked if there could be any connection between the meat in the hamburger and a corn field in Iowa and the paper cup and a tree and to give a reason for their response.

Data Analysis Procedures

For these questions, emergent codes were developed from a sample of student responses. Frequency counts were obtained and student response percentages calculated overall and separately for elementary, middle, and high school students.

Results

Connection between hamburger meat and a corn field

When students were asked, Do you think that there could be any connection between the meat in your hamburger and a corn field in Iowa?, 68.3% of all students answered yes, there could be a connection and 30.8% said no (Figure 8). While 68.3% of the aggregate sample

mentioned that there could be a connection, only 38.2% of elementary school students responded yes, compared to 84.6% of middle school students and 81.8% of high school students.

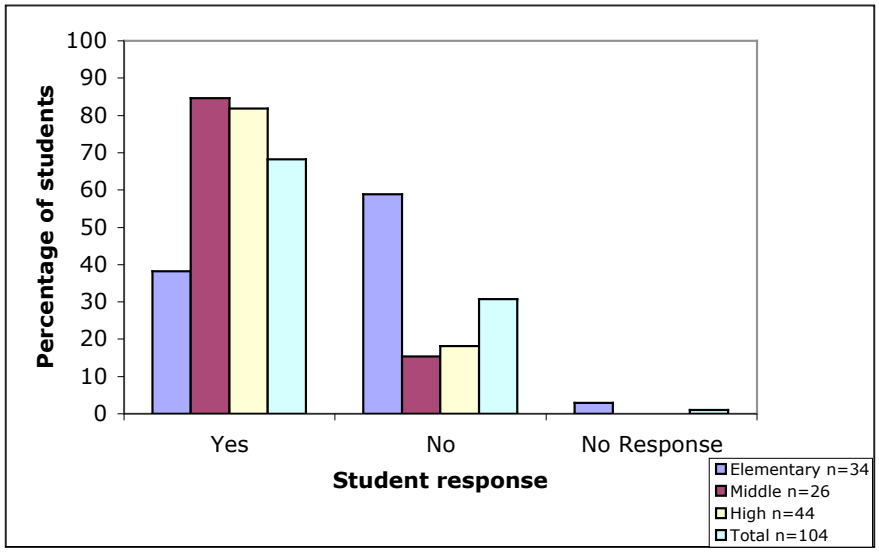


Figure 8. Percentage of student responses to the possibility of a connection between hamburger meat and a corn field in Iowa

Part B of the question asked students to explain why they thought there could or could not be a connection between hamburger meat and a corn field in Iowa. Overall, 34.6% of the students who responded said that there *could* be a connection between hamburger meat and a corn field in Iowa because cows eat corn, code B (Table 1). While 34.6% of all students said that cows eat corn, only 2.9% of elementary students gave this as their reason. Most elementary school students (20.6%), said that there could be a connection between hamburger and a corn field because the cows were raised and the corn grown on the same farm. A small percentage of students (2.9%) provided a more developed explanation by mentioning that cows may eat corn in order to grow – they explained *why* cows might eat corn. Of this 2.9%, 2.8% were middle school students and 4.5% were high school students.

For students who responded that there *could not* be a connection between hamburger meat and a corn field, 19.2% of all students stated that meat and corn are not the same thing. In

other words, meat comes from cows and corn comes from plants (38.2% of the elementary, 3.8% of the middle, and 13.6% of the high school students).

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

2A response	Code	Characteristics of student answers	Elem. (%) n=34	Middle (%) n=26	High (%) n=44	Total (%) n=104
Yes	A	Yes – mentions ***why*** cows might eat corn; specifically relate eating corn to growth of cow	0	**3.8**	**4.5**	2.9
Yes	B	Yes – cows eat corn, but do not mention *why*	2.9	46.2	52.3	**34.6**
Yes	C	Yes – cows on same farm, but no connection between cows eating corn or cows are raised on farms and corn is grown on farms	**20.6**	15.4	13.6	16.3
No	D	No – corn is not the same thing as meat	**38.2**	3.8	13.6	19.2
No	E	No – no relationship; states that there isn't a relationship, but doesn't give any further explanation as to why	2.9	0.0	2.3	1.9
No	F	No	0.0	7.7	2.3	2.9
Yes/No	G	No response	2.9	0.0	0.0	1.0
Yes/No	H	Unintelligible/illegible/answer does not make sense	20.6	3.8	0.0	7.7
Yes/No	I	Other	11.8	23.1	15.9	16.3

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Discussion

There is an increasing awareness of connections between hamburger meat and a corn field as grade level increases. In fact, more elementary students thought that there was *not* a connection between hamburger meat and corn than those who thought there was a connection. In addition, older students increasing traced matter when explaining the connection. A higher percentage of high school students mentioned that cows eat corn (52.3%) or why cows might eat corn (4.5%) than middle school students (cows eat corn: 46.2%; why cows eat corn: 3.8%).

Results

Connections between a paper cup and a tree

In part A of this question, students were asked, Do you think there could be any connections between the paper cup and a tree? Whereas 68.3% of all students mentioned that there could be a connection between hamburger meat and a corn field in Iowa, a higher percentage of all students stated that there could be a connection between a paper cup and tree (97.1%) (Figure 9).

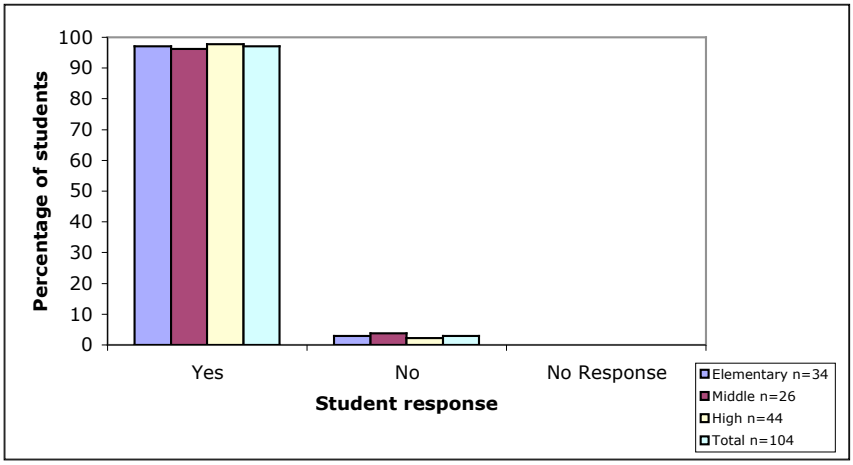


Figure 9. Percentage of student responses to the possibility of a connection between a paper cup and a tree

Part B of the question asked students to explain why they thought there could or could not be a connection between a paper cup and a tree.

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

Code	Response	Elementary (%) n=34	Middle (%) n=26	High (%) n=44	Total (%) n=104
A	Yes – mentions **pulp** or a **process**	0.0	0.0	**11.4**	4.8
B	Yes – specifically mentions the **wood** of the tree, does not mention a process	0.0	**15.4**	4.5	5.8
C	Yes – paper made from trees - does not mention wood or process	**79.4**	57.7	**70.5**	**70.2**

D	Yes – no additional information given other than because it is paper	0.0	7.7	0.0	1.9
*					
F	No – no connection	2.9	3.8	0.0	1.9
G	No response	0.0	0.0	0.0	0.0
H	Unintelligible/illegible	2.9	7.7	0.0	2.9
I	Other	14.7	7.7	13.6	12.5

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*
***In the original pilot study, there was a code E, but this code was eliminated because no student responses fit this code.*

Overall, 70.2% of elementary, middle, and high school students thought that there could be a connection because paper is made from trees (Table 2). Most middle school students mentioned that there was a connection because paper is made from trees (57.7%), but 15.4% gave a more specific answer and mentioned that paper comes from the wood of trees. 70.5% of high school students thought there was a connection between a paper cup and a tree because paper is made from trees, 4.5% stated that paper comes from the wood of a tree, and 11.4% gave an even more detailed answer and mentioned that the tree underwent some type of process, such as the wood was made into pulp or simply that the tree was processed, in order to be made into a paper cup. Students who said that there was not a connection between a paper cup and a tree stated that there was no connection without giving further explanation.

Discussion

There is more awareness of the connection between a paper cup and a tree than hamburger meat and a corn field. Similar to the hamburger meat and corn field question, there is an increasing awareness as grade level increases of connections between a paper cup and a tree. High school students gave more detailed reasons for the connection than middle school and elementary school students; 11.4% of high school students mentioned some type of processing,

while no middle school or elementary school students included processing in their explanations. Elementary school students most often explained the connection between a paper cup and a tree by stating that the paper cup is made from a tree.

Washing Dishes

Handwashing and Dishwasher Question

The handwashing and dishwashing question stated: You have to wash the dishes after dinner every night. You can either hand wash the dishes or use a dishwasher. You use resources to wash the dishes, whether you wash them by hand or using a dishwasher. What resources do you use and what impact does each of these resources have on the environment? Students were asked to fill out tables where they could list the resources in the first column and the impact of the resource in the second column. They filled out one table for handwashing and a second table for using a dishwasher.

While the hamburger meat question asked students to specifically trace the supply chain of the hamburger meat and the paper cup question asked students to trace the waste disposal chain of the paper cup, this question did not explicitly ask students to connect a product to its supply or waste disposal chain. Instead, it 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.

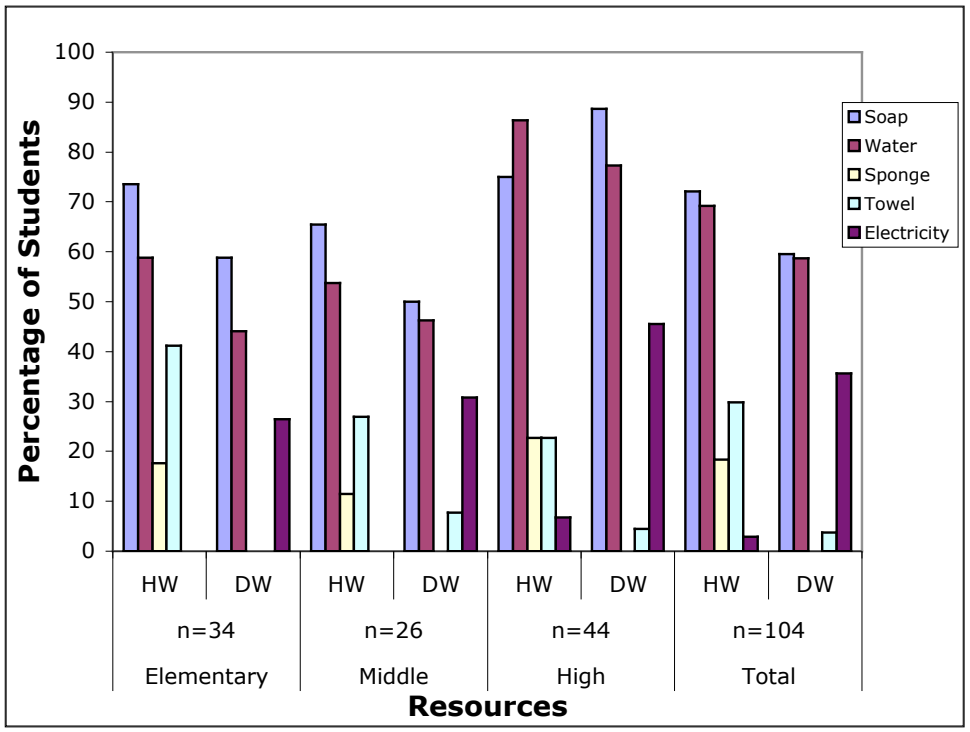
Data Analysis Procedures

Student answers for resources used were coded according to the following: soap, water, sponge, towel/cloth, electricity/energy/heat, other, unintelligible, and no response. The impact

that using these various resources was coded in terms of supply and waste disposal chains (See Table 3).

Results

Overall, the resources most often mentioned by students as resources used in both handwashing and using a dishwasher to wash dishes were soap and water (Figure 10). Students mentioned soap as a resource more often when handwashing dishes (72.1%) than when using a dishwasher (59.6%). They also mentioned water more often when handwashing dishes (69.2%) than using a dishwasher (58.7%). 35.6% of all students mentioned electricity as a resource used when using a dishwasher (26.5% of elementary, 30.8% of middle, and 45.5 % of high school students). Only 2.9% of all students mentioned electricity used when handwashing dishes, and all of them were high school students.



**HW = handwashing, DW = dishwasher*

Figure 10. Percentage of students who mentioned resources used when handwashing or using a dishwasher to wash dishes

For each resource, the impact was coded in terms of supply and waste disposal chains according to the following categories described in table 3 below.

Table 3. Explanation of codes for impact of resources on the environment

Label	**Characteristics of student answers**	**Student explanation**
A	Supply chain - Mentions of less available amount of resource	Less of it Uses up ____ (resource) Wasted
B	Supply chain – refers to something that is used to make the resource; usually refers to materials needed to make a towel/cloth	Made from _____ "Using stuff to make it" "Its made of cotton it uses cotton" – referring to towel
C	Waste disposal chain - Dirty resource – pollution of resource mentioned; usually refers to water becoming dirty after it is used to wash dishes	"water polluted" when referring to water as the resource
D	Waste disposal chain - Pollution – refers to resource polluting something other than itself (soap polluting water or ground)	Includes "could kill animals" Soap "can harm plants" Soap "makes water soapy"
E	No impact	
F	Don't know	
G	UI – Unintelligible; When student answer does not answer the question	"Washing them" – does not answer question of what resources are used and the impact of resources on the environment
H	NR – No response	
I	Other - Responses were coded as *other* when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.	

Overall, 24.5% of the students who mentioned soap as a resource used in handwashing dishes and 27.4% of who mentioned it for using a dishwasher said that soap had no impact on the environment (code E). When handwashing dishes, 17.3% of all students said soap impacts the environment because it polluted or harmed animals, plants, or water and 19.4% responded in the same manner for dishwashing (code D). While the highest percentage of students mentioned the

effect of soap on the environment via a waste disposal chain, the highest percentage of students mentioned the impact of water on the environment in terms of the supply chain. When handwashing dishes, 27.8% of all students mentioned that using water means there is less water available and 27.9% of students gave the same reason when using a dishwasher (code A). Once again, a relatively large percentage of students stated that using water to hand wash dishes or use a dishwasher (22.6% and 26.2% respectively) had no impact on the environment (code E). 27% of all students mentioned that the use of electricity resulted in there being less electricity (code A).

More analysis needs to be done on this question to determine differences amongst elementary, middle, and high school students.

Discussion

This question 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. While students most often mentioned water and soap as resources used when washing dishes, they rarely mentioned electricity. Some students did mention electricity, but no elementary or middle school students and only 6.8% of high school students mentioned it in the handwashing scenario even though electricity is used in both handwashing and using a dishwasher to wash dishes (Appendix E). 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. They must understand the various resources that are involved in bringing goods and services to us and the waste using them puts back into the environment.

Awareness or knowledge of a major environmental issue

Global Warming/Global Climate Change Question

This question asked students questions about a major environmental issue: global warming, also called global climate change. Part A asked students if they had ever heard of global warming, part B asked students what they think causes global warming, and part C asked students how they think global warming can be reduced.

Data Analysis Procedure

For this question, only students who responded yes to part A, Have you ever heard of global warming/global climate change,? were coded for parts B and C.

Results

For part A, Have you ever heard of global warming (also called global climate change)?, 73.1% of all students have heard of global warming (Figure 11). While 73.1% of all students have heard of global warming, 44.1% of elementary, 69.2% of middle, and 97.0% of high school students responded that they have heard of it. A higher percentage of elementary students, 50.0%, responded that they have not heard of global warming than those that have.

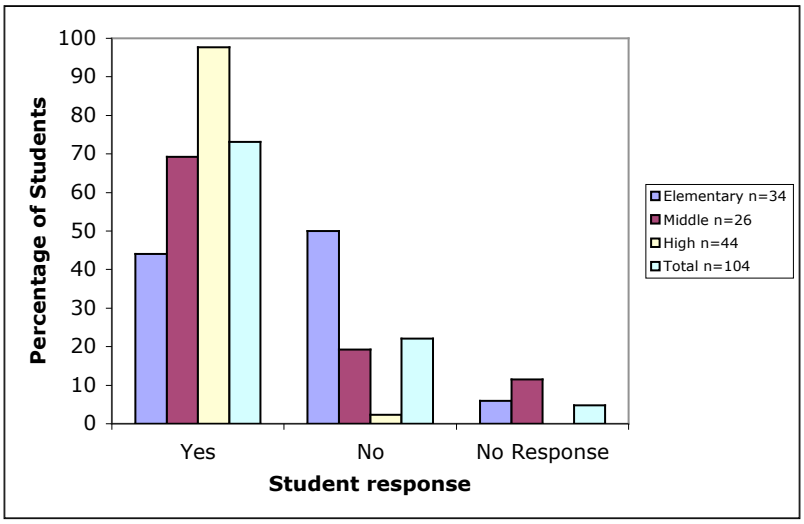
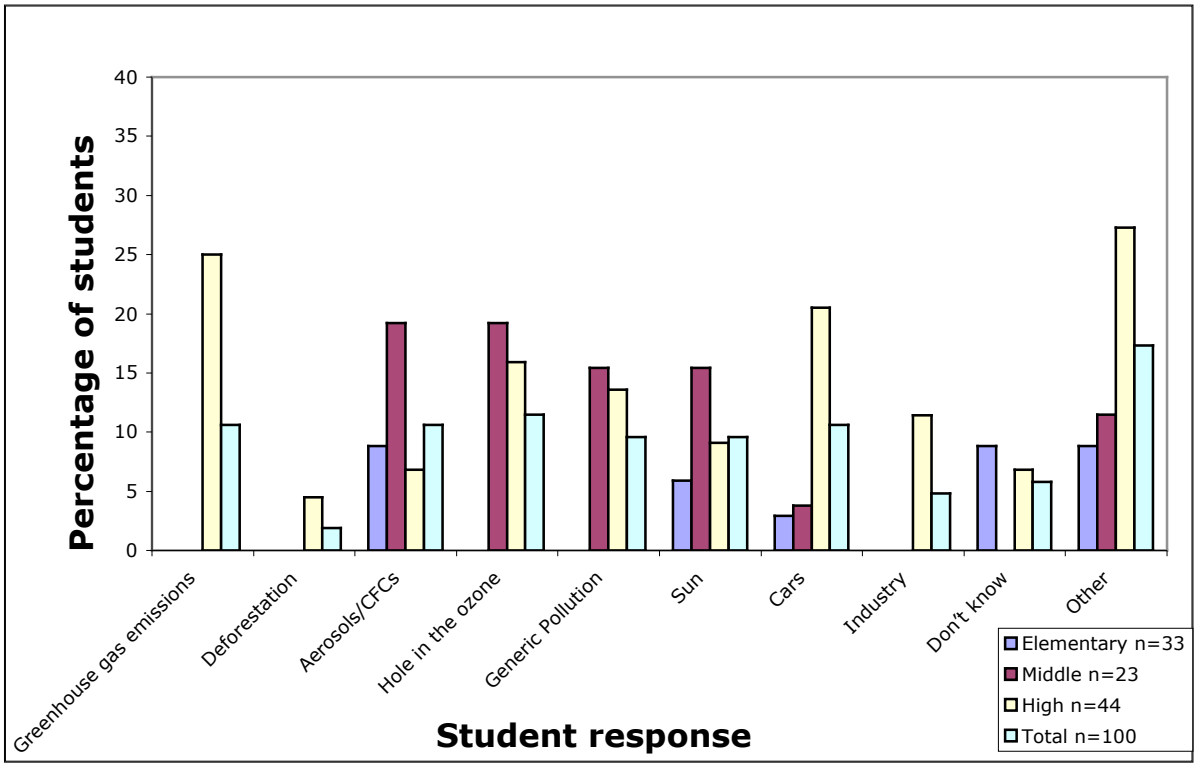


Figure 11. Percentage of student responses to awareness of global warming



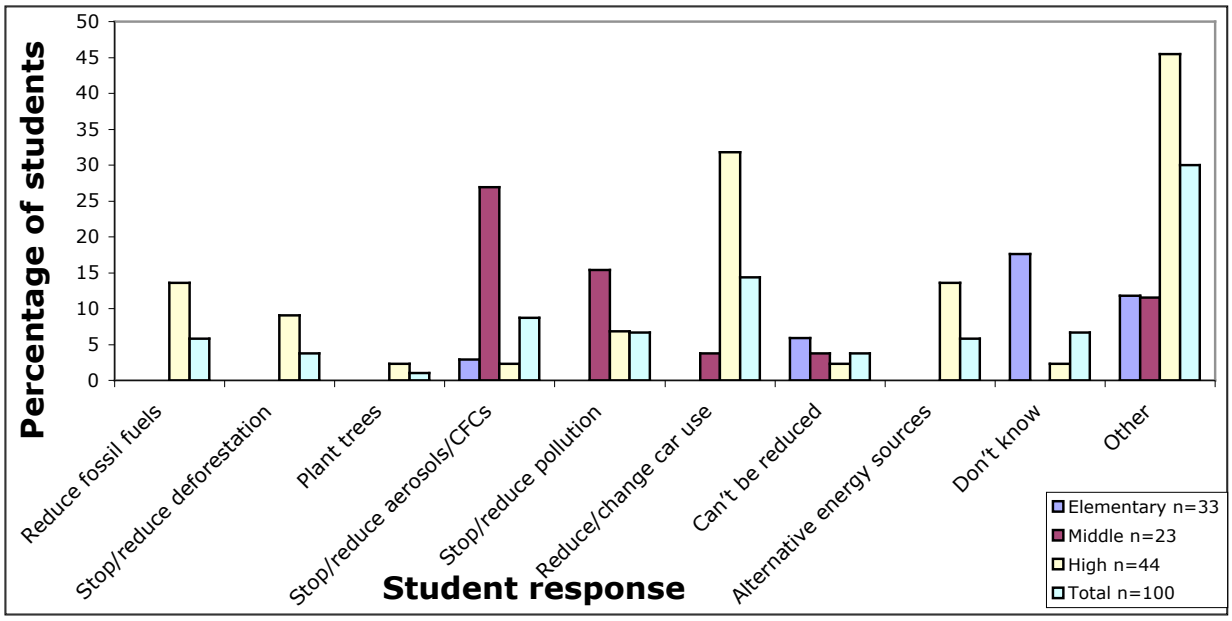
Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Figure 12. Percentage of student responses for cause of global warming

For part B, What do you think causes global warming/global climate change? 25% of high school student responses mentioned that global warming is caused by *greenhouse gas*

emissions or mention a specific type of greenhouse gas such as *carbon dioxide*, but no middle school or elementary school students mentioned greenhouse gases as a cause of global warming (Figure 12). Middle school students most commonly mentioned *CFCs* or *aerosol sprays* as a cause of global warming (19.2%) and they often stated a *hole in the ozone* (19.2%) causes global warming, usually directly connecting the hole in the ozone to CFCs. 20.5% of high school students responded that *cars*, car exhaust, or pollution from cars causes global warming. This was coded separately from greenhouse gas emissions, because students did not specifically mention carbon dioxide or fossil fuels.

Part C asked students, how do you think global warming/global climate change can be reduced? The highest percentage of all students, 14.4%, mentioned that it can be reduced by some means related to cars, such as driving less or using alternatively powered cars (Figure 13). While 31.8% of high school students responded in this manner, only 3.8% of middle school students and no elementary school students mentioned changes in car use as a means of reducing global warming. Middle school students most often mentioned something related to reducing or stopping the use of aerosol spray cans, CFCs, chemicals, or pesticides as a way to reduce global warming (26.9%). Elementary school students most often stated that they did not know how to reduce global warming (17.6%).



*Responses were coded as *other* when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.

Figure 13. Percentage of student responses for ways to reduce global warming

Discussion

Analysis of this question brings up several key ideas. First, more high school than middle or elementary school students have heard of global warming. In addition, older students progressively demonstrate a better understanding of the causes and ways to reduce global warming. Among the causes of global warming, only high school students mentioned greenhouse gases and deforestation, which are primary contributors to global warming. Also, more high school students than middle school or elementary school students mentioned cars as a cause of global warming. Furthermore, high school students are more specific in their responses as to the causes and ways to reduce global warming. More middle school and elementary school students tended to respond that *pollution* causes global warming, without mentioning the source of the pollution (i.e., cars, buildings) or the particular type of pollution (i.e., fossil fuels). In order for

students to recognize ways in which global warming can be reduced, they must first understand the causes of global warming.

Discussion

Humans take matter and energy from natural systems and return them back to natural systems. At each step of supply chains and waste disposal chains, various human engineered and natural systems interact. This paper examines data regarding three **large-scale systems and processes**: a hamburger supply chain, a paper cup waste disposal chain, and a dishwashing supply and waste disposal chain. In our discussion, we will focus on these large-scale systems and processes and student understanding of them in terms of the following:

- **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.
- **Tracing matter and energy:** Did students mention matter in their depictions of supply and waste disposal chains? If they did, what matter did they mention? Did they mention energy?
- **Processes/Transformation of matter and energy:** Did students simply mention matter and energy 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? What transformations of matter and energy did students mention?
- **Infrastructure and by-products**: Systems and processes require infrastructure that connects various steps or stages of the systems and processes. What aspects of infrastructure did students mention? Each step of systems and processes create by-products that enter back into

natural systems. What by-products did students mention and what was the impact of these by-products?

In the first section, we will discuss how students generally depicted the large-scale systems and processes, particularly supply and waste disposal chains, in terms of actors and locations. In the next two sections, we will examine how students traced matter and energy through large-scale systems. In the following section, we address the types of infrastructure and by-products students mentioned. Then, we will talk about the possible implications these findings have for a learning progression. Finally, we will use results from the global warming question to ground our argument about implications of students' scientific knowledge of supply and waste disposal chains, which are means by which human engineered systems and natural systems are connected, and their ability to reason scientifically for responsible citizenship.

Actors and locations/places

Students described supply and waste disposal chains as sequences of actors and 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 *butcher*. Before that, the hamburger meat came from a *cow* on a *farm*. In this supply chain, students focused on actors - a butcher and cow, and places – stores and farms. 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 feed lots are in none.

Students described the paper cup waste disposal chain mainly as a series of locations/places. Students described either a garbage waste disposal chain or a recycling waste

disposal chain. A typical students' garbage waste disposal chain stated that the student would first throw the paper cup in the *trash can*. After that, the trash can would be dumped into the school *dumpster*. Then, the *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 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. In both the hamburger supply chain and the paper cup waste disposal chain, students described the actors and locations/places when tracing the products.

Matter and Energy

In the hamburger supply chain and paper cup waste disposal chain, students focused on tracing matter through various actors and locations, rather than on the transformation of matter on an atomic-molecular level, which will be discussed next. Students also did not focus on energy. The dish washing question asked students to list resources used when handwashing and using a dishwasher to wash dishes, and the impact using those resources has on the environment. Students most often mentioned matter as resources, but rarely mentioned energy. They listed familiar resources such as soap and water. Only high school students mentioned electricity or energy as a resource used when washing dishes. When they did mention it, they more often mentioned it as a resource used by a dishwasher. They rarely mentioned it as a resource used when handwashing dishes even though energy is needed to heat water when handwashing dishes.

Processes/Transformation of matter

While most students traced matter (hamburger meat and paper cup) through actors and locations/places in their depictions of supply and waste disposal chains, they rarely traced the matter transformation on an atomic molecular scale. Thus, in the hamburger supply chain more students mentioned *farm* than the *plants* that the cow eats on the farm in order to grow. The places that the meat goes are much more prominent than the form or transformation of the meat. When asked to explain why there could be a connection between hamburger meat and a corn field, most students mentioned that cows eat corn. Students were not explicitly asked to trace matter, but there is some evidence of tracing matter and its transformation, as a few students provided more detailed answers and stated that cows eat corn, which helps cows to grow.

Student explanations for the connection between a paper cup and a tree focused on matter but not the transformation of matter on an atomic molecular scale. Most students explained that there could be a connection because paper is made from trees and some students specifically stated that paper is made from the wood of trees. A few students specifically mentioned that the wood of trees must go through some type of process in order to be turned into paper – which focuses on the transformation of matter.

In the garbage waste disposal chain, some students mentioned that the trash sits at the landfill, but some stated that the paper cup would decompose and return to the soil. Although students who mentioned that the paper cup would decompose may not have understanding of the structure of a landfill (they may not realize that the landfills are carefully designed so that garbage is isolated from the surrounding environment so as not to pollute ground water and products from the breakdown of trash such as methane do not harm the environment) and constraints of human engineered systems on processes such as decomposition that occur in

natural systems, they recognized that the waste disposal chain consisted of more than actors and places.

Infrastructure and by-products

Large-scale systems and processes require infrastructure and generate by-products. 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. Some students mentioned infrastructure in the form of transportation such as a garbage truck that moved the hamburger meat or paper cup from one location to another.

In the handwashing/dishwasher question, students mentioned resources used to wash dishes such as water, soap, and towels. When asked what impact using these resources has on the environment, students often responded "none." They did not demonstrate knowledge of the impact that using various resources has on the environment. For water, when students did recognize some impact on the environment, they often stated that there would be "less water." Students less often mentioned the impact in terms of waste disposal chains and the resulting by-product – polluted water. When students mentioned energy as a resource, students also stated that there would be "less" energy. They did not mention that energy use could lead to by-products that pollute the environment. 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. These students recognized that a by-product of using soap may be harmful to the environment, such as animals and plants.

Learning Progression

From analysis of the assessment, we have come up with some possible ideas about a learning progression related to supply and waste disposal chains.

- **Actors and location/places.** Students generally depicted supply and waste disposal chains in terms of actors and location/places. The *number of steps* (actors and places) mentioned in supply and waste disposal chains is significantly associated to school level (elementary, middle, and high). Elementary school students mentioned the fewest steps and high school students mentioned the most steps when tracing supply and waste disposal chains.
- **Tracing matter and energy.** Students mentioned *matter* more often than they mentioned *energy*. When students did mention energy, it was high school students, as opposed to elementary school students. Students of all ages failed to recognize the role of energy consumption in supply chains and waste disposal chains. For example, only 6.8% of the high school students (and none of the elementary or middle school students) mentioned energy to heat the hot water as an environmental impact of handwashing dishes.
- **Processes/Transformation of matter and energy.** In general, more high school students mentioned some type of *transformation of matter*. In the paper cup recycling waste disposal chain, more high school students than middle or elementary school students mentioned some process that the paper cup undergoes in order to be recycled and made into a new product. When explaining the possible connection between hamburger meat and a corn field, a small percentage of high school and middle school students mentioned that cows eat corn in order to grow while no elementary school students gave this reason. Elementary students who saw a connection explained that cows and corn exist on the same farm; they did not mention that cows may eat corn. In their rationales for the connection between a tree and a paper cup, only

high school students mentioned some process that the tree had to go through in order for paper to be made.

- **Connections between human and natural systems.** In part because they were describing sequences of locations and events rather than transformations in matter and energy, students were generally vague about how human supply chains and waste disposal chains were connected with natural environmental systems.
- **Infrastructure and by-products.** Systems and processes require *infrastructure* that connects various steps or stages of the systems and processes. While more middle school than elementary or high school students mentioned transportation, a form of infrastructure that connects steps, in the hamburger supply chain, more high school than elementary or middle school students mentioned transportation in the paper cup waste disposal chain. Therefore, it is difficult to determine if high school students recognize infrastructure more often than elementary or middle school students from this data. In the dish washing question, more high school students mentioned an impact that using resources has on the environment. One way to view impact on environment is in terms of the *by-products* that the dish washing process creates. Elementary school students most often mentioned that using resources had no impact on the environment. (Elementary students may have had trouble understanding the question due to the difficulty of its wording. They may not have known what *resources* and *impact* meant.)

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.) and the connections between human engineered and natural systems. The first step may be in teaching students 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 feed lots. It is important for students to be familiar with feed lots because they create much waste (by-products) that enters into the environment and can have severe negative consequences such as polluting water supplies. 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, and 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.

Using scientific reasoning for responsible citizenship

Most students have an incorrect understanding of the causes of global warming/global climate change and how human systems impact natural systems. When students were asked what they think causes global warming/global climate change, students often stated a hole in the ozone layer and/or CFCs and aerosol cans as the cause. These reasons are not grounded in scientific knowledge and reasoning, and while we do not have any evidence, these responses may come more from media and personal experience than formal science education. The major causes of

global warming/global climate change are fossil fuel emissions[1] and changes in land use. Some students mentioned pollution as a cause of global warming, but in general terms without naming sources of pollution. Some high school students (no middle or elementary school students) listed fossil fuel emissions or carbon dioxide or land use such as deforestation as causes of global warming.

Students were also asked ways in which global warming/global climate change can be reduced. In order for students to understand causes of global warming and how it can be reduced, they must understand supply and waste disposal chains such as energy supply chains. These human engineered supply chain systems take natural resources from the natural environment and transform the energy for human use. In the process, by-products from these processes enter back into natural systems and can cause major environmental problems such as global warming. If students have scientific understanding of these processes and recognize how human engineered and natural systems are connected, then they can understand the role that humans play in environmental issues like global warming. They can think about how various decisions that humans make have different degrees of positive or negative impact on the environment and think about the efficiency of human actions and systems. It is crucial that students understand how human engineered and natural systems are connected in order to make responsible decisions as citizens and stewards of our environment.

[1] While CFCs are a fossil fuel, they have limited influence on global warming/climate change. Global warming is contributed to other fossil fuels such as carbon dioxide.

Appendix A

Question 1:

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. Fill in the table below with your ideas about what it was and where it came from before it came to the school cafeteria. Trace the beef back as far as you can.

	What was it? Where did it come from?
	Ground beef in hamburger in the school cafeteria
Before that…	
Before that…	
Before that…	
Before that…	
Before that…	
Before that…	

Appendix B

Table B1. Percentage of Student Responses of Steps in Hamburger Supply Chain

Code	**Elementary (%) n=34**	**Middle (%) n=26**	**High (%) n=44**	**Total (%) n=104**
Package	14.7	23.1	22.7	20.2
Visible storage	76.5	61.5	79.5	74.0
Transportation	26.5	38.5	25.0	28.8
Meat processing/butcher	35.3	61.5	79.5	60.6
Slaughterhouse	5.9	19.2	34.1	21.2
Farm	29.4	50.0	68.2	51.0
Cow	85.3	92.3	88.6	88.5
Parent	14.7	34.6	15.9	20.2
Growth	29.4	46.2	27.3	32.7
Plants (i.e., food for cows)	2.9	2.8	13.6	7.7
Other*	14.7	7.7	22.7	16.3

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Appendix C

Table C1. Percentage of Student Responses of Type of Paper Waste Disposal Chain

Code	Response	Elementary (%) n=34	Middle (%) n=26	High (%) n=44	Total (%) n=104
A	Garbage	58.9	42.3	40.9	47.1
B	Recycle	32.4	38.5	34.1	34.6
C	Combination –mention both recycling and garbage		15.4	22.7	13.5
D	Unintelligible	5.9	0.0	0.0	1.9
E	No response		0.0	0.0	
F	Other - Includes mention of garbage as way of disposing of cup, but wants to recycle (no recycling available)	5.9	11.5	6.8	7.7

Table C2. Percentage of Student Responses of Waste Disposal Chain Steps

Waste disposal chain	Response	Elementary (%) n=34	Middle (%) n=26	High (%) n=44	Total (%) n=104
Trash	Trash can	32.4	42.3	38.6	39.4
	Dumpster	5.9	23.1	18.2	15.4
	Landfill	29.4	11.5	34.1	26.9
	Junkyard	2.9	3.8	2.3	2.9
	Buried	8.8	3.8	9.1	7.7
	Decompose	11.8	30.8	20.5	20.2
	Burn	2.9	7.7	2.3	3.8
Both	Transportation	23.5	6.9	40.1	42.3
Recycle	Recycling bin	5.9	23.1	22.7	17.3
	Recycling place	5.9	23.1	27.3	19.2
	Separate/sorted	0.0	3.8	2.3	1.9
	Processed	17.6	19.2	25.0	10.6
	New product	14.7	26.9	25.0	22.1
	Other*	20.6	54.8	34.1	34.6
	UI	5.9	0.0	0.0	1.9
	NR	5.9	0.0	0.0	1.9

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Appendix D

Table 1D. Percentage of Student Responses of a Possible Connection between Hamburger Meat and a Corn Field in Iowa

Response	**Elementary (%) n=34**	**Middle (%) n=26**	**High (%) n=44**	**Total (%) n=104**
Yes	38.2	84.6	81.8	68.3
No	58.8	15.4	18.2	30.8
No Response	2.9	0	0	1.0

Table 2D. Percentage of Student Responses of a Possible Connection between a Paper Cup and a Tree

Response	**Elementary (%) n=34**	**Middle (%) n=26**	**High (%) n=44**	**Total (%) n=104**
Yes	97.1	96.2	97.7	97.1
No	2.9	3.8	2.3	2.9
No Response	0	0.0	0.0	0.0

Appendix E

Table E1. Percentage of Student Responses of Resources Used When Handwashing (HW) and Using a Dishwasher (DW) to Wash Dishes

Response	**Elementary (%) n=34**		**Middle (%) n=26**		**High (%) n=44**		**Total (%) n=104**	
	HW	***DW***	***HW***	***DW***	***HW***	***DW***	***HW***	***DW***
Soap	73.5	58.8	65.4	50.0	75.0	88.6	72.1	59.6
Water	58.8	44.1	53.8	46.2	86.4	77.3	69.2	58.7
Sponge	17.6	0.0	11.5	0.0	22.7	0.0	18.3	0.0
Towel	41.2	0.0	26.9	7.7	22.7	4.5	29.8	3.8
Electricity	0.0	26.5	0.0	30.8	6.8	45.5	2.9	35.6
Other	44.1	114.7	34.6	61.5	22.7	36.4	32.7	68.3
Unintelligible	2.9	2.9	3.8	7.7	0.0	0.0	1.9	2.9
No response	5.9	5.9	26.9	23.1	9.1	9.1	12.5	11.5

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Table E2. Total Percentage of Student Responses for Impact of Resource on the Environment

Reason	**Soap**		**Water**		**Sponge**		**Towel**		**Electricity**	
	HW n=75	**DW** n=62	**HW** n=72	**DW** n=61	**HW** n=19	**DW** n=0	**HW** n=31	**DW** n=4	**HW** n=3	**DW** n=37
A	5.3	6.5	27.8	27.9	10.5	-	-	-	66.7	27.0
B	5.3	6.5	-	-	5.3	-	6.5	-	-	5.4
C	-	-	4.2	8.2	-	-	-	-	-	-
D	17.3	19.4	2.8	1.6	10.5	-	-	-	-	5.4
E	24.0	27.4	22.2	26.2	26.3	-	35.5	25.0	-	16.2
F	8.0	3.2	1.4	1.6	5.3	-	9.7	-	-	2.7
G	18.7	16.1	15.3	13.1	15.8	-	25.8	50.0	-	2.7
H	9.3	11.3	5.6	4.9	21.1	-	9.7	25.0	-	10.8
I	13.3	9.7	23.6	18.0	5.3	-	12.9	-	33.3	29.7

**Percentages were calculated from the total number of students who mentioned the resource, not from the total number of students overall.*

Appendix F

Table F1. Percentage of Student Responses of Awareness of the term *Global Warming/Global Climate Change*

Response	**Elementary (%) n=34**	**Middle (%) n=26**	**High (%) n=44**	**Total (%) n=104**
Yes	44.1	69.2	97.7	73.1
No	50.0	19.2	2.3	22.1
No Response	5.9	11.5	0.0	4.8

Table F2. Percentage of Student Responses of Causes of Global Warming/Global Climate Change

Code	**Response**	**Elementary (%) n=33**	**Middle (%) n=23**	**High (%) n=44**	**Total (%) n=100**
A	Greenhouse gas emissions, such as carbon dioxide	0	0	25.0	10.6
B	Deforestation/Land use	0	0	4.5	1.9
C	Aerosols/CFCs/chemicals/pesticides	8.8	19.2	6.8	10.6
D	Hole in the ozone	0	19.2	15.9	11.5
E	Pollution – response mentions pollution in general, do not specifically mention type/cause of pollution	0	15.4	13.6	9.6
F	Sun – Sun, sun rays cause the earth to warm, ice to melt	5.9	15.4	9.1	9.6
G	Cars – mention cars, car exhaust, pollution from cars	2.9	3.8	20.5	10.6
H	Response attempts to define global climate change instead of explaining *causes* of it	8.8	11.5	2.3	15.9
I	Don't know	8.8	0	6.8	5.8
J	Other	8.8	11.5	27.3	17.3
K	Unintelligible	2.9	0	0	1.0
L	No response	0	0	4.5	1.9
M	Industry	0	0	11.4	4.8

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

Table F3. Percentage of Student Responses of how global warming/global climate change can be reduced

Code	Response	Elementary (%) n=33	Middle (%) n=23	High (%) n=44	Total (%) n=100
A	Reduce fossil fuels or carbon dioxide emissions			13.6	5.8
B	Stop/reduce deforestation			9.1	3.8
C	Plant trees			2.3	1.0
D	Stop/reduce use of aerosols/CFCs/chemicals/pesticides	2.9	26.9	2.3	8.7
E	Stop polluting/less pollution – does not specifically mention type of pollution		15.4	6.8	6.7
F	Mentions driving vehicles less, or alternatively powered cars		3.8	31.8	14.4
G	Can't be reduced	5.9	3.8	2.3	3.8
H	Don't know	17.6		2.3	6.7
I	Other	11.8	11.5	45.5	30.0
J	UI	5.9	7.7	2.3	4.8
K	NR		7.7	6.8	11.4
L	Alternative energy sources/ Conservation – Generic alternative energy sources or specific non-car energy sources			13.6	5.8

Responses were coded as **other when they did not fit into one of the other codes and there were not enough similar responses to constitute creating a code.*

References

Anderson, C. W., Abdel-Kareem, H., Carolan, A., Cho, I.-Y., Covitt, B., Gallagher, J., et al. (January, 2006). *Partial draft: Environmental literacy blueprint*. East Lansing: Michigan State University.

Andersson, B., & Wallin, A. (2000). Students' understanding of the greenhouse effect, the societal consequences of reducing CO2 emissions and the problem of ozone layer depletion. *Journal of Research in Science Teaching, 37*(10), 1096-1111.

Boyes, E., & Stanisstreet, M. (1998). High school students' perceptions of how major global environmental effects might cause skin cancer. *The Journal of Environmental Education, 29*(Winter), 31-36.

Boyes, E., Stanisstreet, M., & Papantoniou, V. S. (1999). The ideas of Greek high school students about the "ozone layer". *Science Education, 83*, 724-737.

Calabrese Barton, A., Koch, P. D., Contento, I. R., & Hagiwara, S. (2005). From global sustainability to inclusive education: Understanding urban children's ideas about the food system. *International Journal of Science Education, 27*(10), 1163-1186.

Eisenhart, M., Finkel, E., & Marion, S. F. (1996). Creating the conditions for scientific literacy: A re-examination. *American Educational Research Journal, 33*(2), 261-295.

Environmental Visions Committee. (2004). *Ecological science and sustainability for a crowded planet: 21st century vision and action plan for the Ecological Society of America*: Ecological Society of America.

Francis, C., Boyes, E., Qualter, A., & Stanisstreet, M. (1993). Ideas of elementary students about reducing the "greenhouse effect". *Science Education, 77*(4), 375-392.

Intergovernmental Panel on Climate Change. (2001). Summary for policymakers. In *Climate change 2001*.

Jeffries, H., Stanisstreet, M., & Boyes, E. (2001). Knowledge about the 'greenhouse effect': have college students improved? *Research in Science & Technological Education, 19*(2), 2001.

Kempton, W. (1997). How the public views climate change. *Environment, 39*(9), 12-21.

Kempton, W., Boster, J. S., & Hartley, J. A. (1995). *Environmental values in American culture*. Cambridge, MA: The MIT Press.

Lester, B. T., Ma, L., Lee, O., & Lambert, J. (2006). Social activism in elementary science education: A science, technology, and society approach to teach global warming. *International Journal of Science Education, 28*(4), 315-339.

Millennium Ecosystem Assessment. (2005). Summary. In *Ecosystem and human well-being: A framework for assessment* (pp. 1-25).

Tsurusaki, B., K. (2006). *Environmental literacy working paper: Analysis procedures for connecting actions to environmental systems*. East Lansing, MI: Michigan State University.

U.S. Environmental Protection Agency Science Advisory Board. (2000). Toward integrated environmental decision-making. Retrieved September 9, 2005, from http://www.epa.gov/sab/pdf/ecirp001.pdf