Students' understanding of connections between human engineered and natural environmental systems: Similarities and differences across grade level and context

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Abstract

This research, which is part of a larger environmental science literacy project, 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 (see AC-ERE, 2003). 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 two major environmental issues – global warming and preserving our forests. Assessments were administered to elementary, middle, and high school students from rural, suburban, and urban schools. We found that students had vague and incomplete understandings of supply and waste disposal chains and environmental issues. Many steps and processes in supply and waste disposal chains were "invisible" to students, particularly some steps that have the greatest impact on our natural environment. We center our discussion around two themes: 1) student awareness of how the goods and services they depend on come from and return to natural systems; and 2) students' appreciation of the nature of the environmental impact of the goods and services they use. In order to address these themes, we discuss student understanding of the actors and locations/places, infrastructure and by-products, and transformation of matter and energy involved in supply and waste disposal chains and environmental problems.

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 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" (Aikenhead, 1994, pp. 48-49). The SSI movement has a growing body of research, as evidenced by the April 2006 issue of the Journal of Research in Science Teaching, which was devoted to socioscientific concerns (Baker & Piburn, 2006). 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 STS with its explicit attention to ethical aspects of social issues that are tied to science (Sadler, Amirshokoohi, Kazempour, & Allspaw, 2006).

This research, which is part of a larger environmental science literacy project, draws on aspects of and fits within the goals and efforts of both the STS and SSI movements. It extends 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., April, 2006; Smith, Wiser, Anderson, & Krajcik, in press). 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, 2003). These advances in the natural sciences lead us to advocate changes in the science curriculum that refocus the curriculum on *environmental literacy and responsible citizenship*. This paper reports the results of elementary, middle, and high school students from rural, urban, and suburban schools understanding of the connection between human engineered and environmental systems.

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. In just the past year, 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” and Michael Pollan’s book, *Omnivore’s Dilemma* (Pollan, 2006) – all attempts to inform the public about the role that humans play in environmental issues. The heightened attention given to environmental 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.

Therefore, we have set forth the agenda of teaching students to be environmentally literate - 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 four key practices of environmental science literacy (Anderson et al., April, 2006):

1. Scientific inquiry: developing and evaluating scientific arguments from evidence,[1]
2. Scientific accounts: using scientific accounts of the material world,
3. Application: using scientific accounts as tools to predict and explain, and
4. Citizenship: using scientific reasoning for responsible citizenship.

Connecting human actions with environmental systems

This particular paper focuses on what students know about connections between human engineered and environmental systems. While 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, 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. In particular, it focuses on a

[1] Along with Anderson, et al. (2006), also see the Michigan Department of Education. (August, 2006). High school content expectations: Biology draft for more information about scientific inquiry, scientific accounts, and application.

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, third, and fourth 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, 3 and 4)

This paper build on previous work for this project which analyzed student understanding of supply and waste disposal chains and environmental issues (B. K. Tsurusaki & Anderson, April, 2006). The first study examined a smaller sample of students from mainly rural schools. This paper 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 differ by grade level (elementary, middle, high school)?

Data Collection and Analysis

Assessment Questions

Because little previous research is available regarding students' knowledge of how human actions are connected to environmental systems, the assessment items were based on the experiences of members of the research 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). This paper examines data regarding three *large-scale systems and processes*: a hamburger supply chain, a paper cup waste disposal chain, dishwashing supply and waste disposal chain. It also addresses two *environmental issues*, global warming and the preservation of forests, which are impacted by supply and waste disposal chains (Table 1).

Table 1

Connecting actions assessment questions

	Assessment questions
1.	Where did the hamburgers come from?
2.	How would you get rid of a paper cup and what might happen to it?
3.	Do you think that there could be any connection between the meat in your hamburger and a corn field in Iowa? Explain why you think this.
4.	You drink some water from a paper cup from the school cafeteria. Do you think there could be any connections between the paper cup and a tree? Explain why you

	think this.
5.	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?
6.	a. Have you ever heard of global warming (also called global climate change)? b. What do you think causes global warming/global climate change? c. How do you think global warming/global climate change can be reduced?
7.	Why do you think it might be important to preserve our forests?

While questions 1 and 2 specifically asked students to trace the supply chain of hamburger meat and the waste disposal chain of a paper cup, question 5 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.

Supply and waste disposal chains are sources of, or result in, environmental problems. 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. Therefore, we felt it was important to ask students about major environmental problems such as global warming (question 6) and deforestation (question 7) to find out how familiar they are with them and what they know about them. In order for students to understand the causes of global warming, they must understand the science behind it and the role that humans play in global warming. This includes understanding how environmental problems are connected to supply and waste disposal chains. In order for students to understand the impact that deforestation has on the environment, students need to understand the role forests play in the ecosystem and why they are important. Students place some type of value on things in the environment, whether they value things as good, bad, important, or unimportant. We believe that students must see forests as important in order to take actions to preserve forests. Furthermore, it is *possible* that students who better understand why forests are important will take actions in order to preserve them. We believe that students need to understand the science of environmental problems and how they are connected to human actions in order to even begin to address the problems.

Participants

A total of 16 teachers from 14 different schools (6 high school, 6 middle school, 4 elementary school) administered the assessment. Data from 125 elementary school students (34 rural, 46 suburban, 45 urban), 140 middle school students (40 rural, 50 suburban, 50 urban), and 147 high school students (47 rural, 50 suburban, 50 urban) were analyzed (See Appendix B for more information).

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* (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.

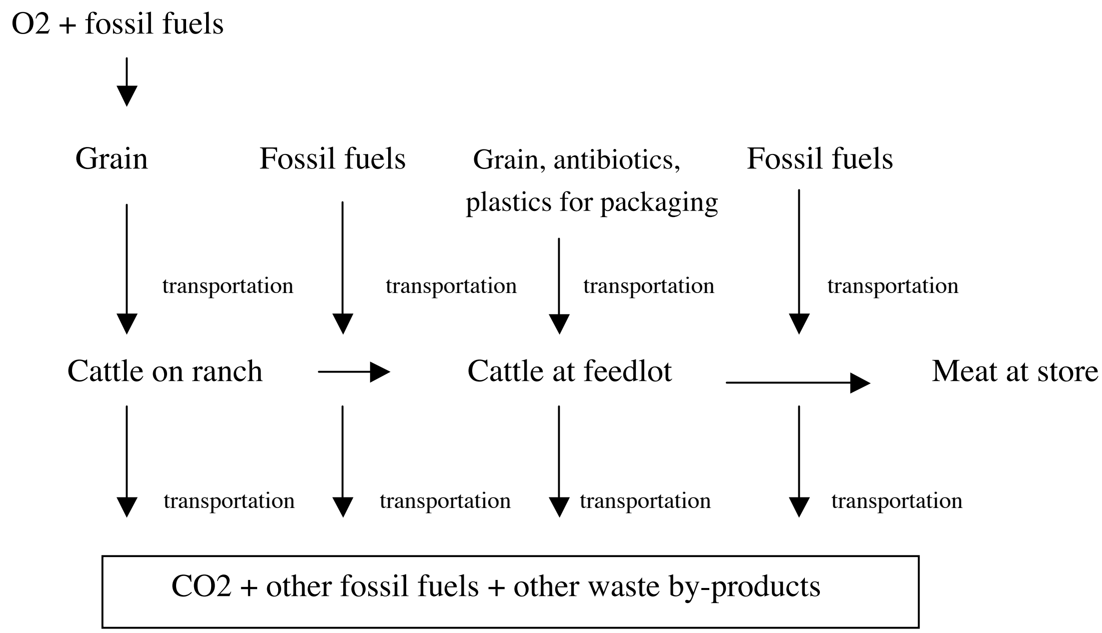


Figure 1. Simple diagram of a hamburger supply chain.[2]

In addition, students need to understand *how matter and energy is transformed* as it passes through supply and waste disposal chains. 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 produced by the systems. Using this framework as a guide, the assessments were analyzed by examining the *actors and locations/places*, *infrastructure and by-products,* and *processes/transformation of matter and energy* the students mentioned in their responses.

[2] This diagram does not include labels with actors, as it is difficult to represent in the diagram.

Data Analysis Procedure

Analysis was guided by a Working Paper, written by the lead author of the paper, with contains rubrics for coding students' responses (B. Tsurusaki, K, 2006). Emergent codes were developed from analysis of a sample of assessments. These codes were then used to develop rubrics, which were designed to highlight aspects of the students' responses relevant to the framework presented in the previous section (actors, locations/places, infrastructure and by-products and transformation of matter and energy), the general theme of environmental literacy and the specific trends in the succession of students' reasoning. We were particularly interested in students' understanding of how we are dependent on natural systems and their understanding of the environmental impacts of our actions. Therefore, we looked for connections between human and natural systems that were commonly mentioned by students and those that were not (e.g., where do students start and end their supply and waste disposal chains?). We were also concerned with any awareness students showed of human impact on the environment. In addition, we were interested in looking at similarities and differences across grade level and context.

Reliability of the rubrics was assessed by having a second coder independently code a sample of the tests. 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 of each question*.

Results

Each section of the results will contain four parts: 1) Question, 2) Data analysis procedures, 3) Data results, 4) Discussion.

Tracing steps in the hamburger supply chain

Hamburger supply chain question

This question on the assessment 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 back the supply chain of the beef as far as they could.

Data Analysis Procedures

We examined the *actions and locations/places*, *transformation of matter*, and *infrastructure and by-products* that students mentioned in their responses. 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. 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).

In addition, 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) 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.

Results

Actors and Location/Places

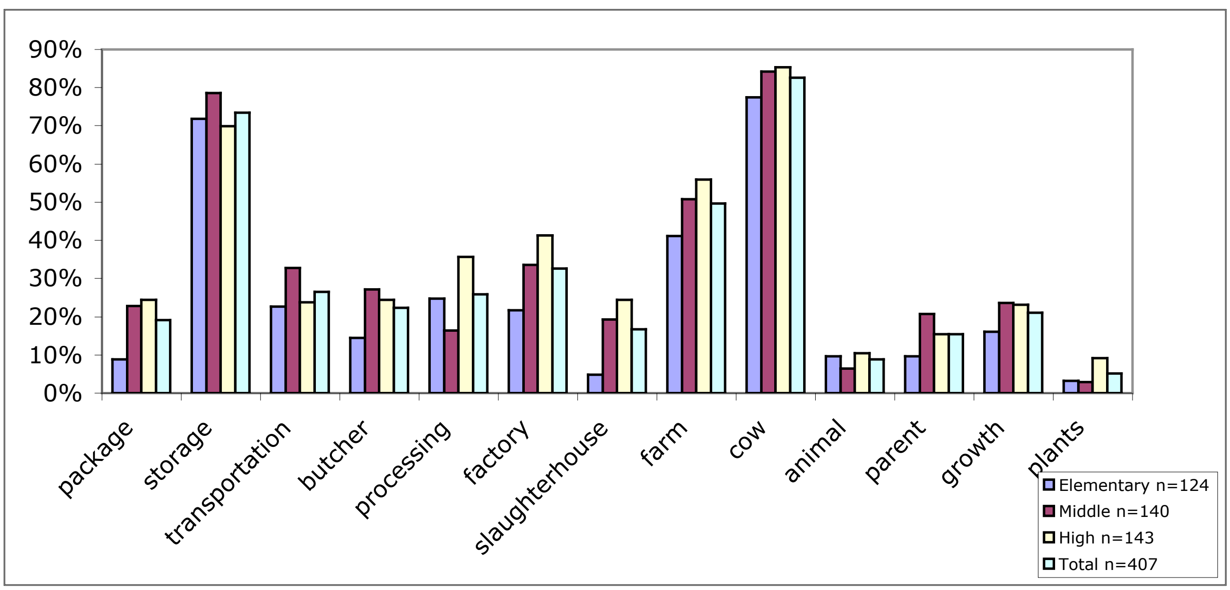
Students generally depicted supply and waste disposal chains in terms of *location/places*. Students most often mentioned “visible storage” such as a freezer or store (73.5%), “farm” (49.6%), and “factory” (32.7%) (Figure 2). While they often included “visible storage” and “farm,” they did not mention ranches and feedlots; their portrayals of the hamburger supply chain was of small-scale family farms, as opposed to large-scale, mass production of beef. Most students, 82.6%, traced the hamburger supply chain back to the “cow,” or more generally an “animal” (8.9%), but only 5.6% of the students mentioned plants that the cows may eat in order to grow (when students did mention something that the cows eat, they mentioned some plants and not feed or corn). Students *rarely mentioned humans* (actors) at any stage of the supply chain. While overall, 22.4% of all students mentioned butcher, 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” and another stated, “in the factory where the people made the hamburger” as step in the supply chain. 2.7% of all students mentioned a “farmer” and 1.2% mentioned a person who transported the hamburger meat from place to place. 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.

Transformation of matter

Student descriptions of how the meat from a cow was transformed into hamburger meat were vague. 21.1% of students recognized some type of growth of the cow (mentioned both a calf and cow, but did not necessarily specifically mention that the cow grew), which could be seen as transformation of matter. Students most often mentioned transformation of matter at the factory or butcher, where the cow meat was cut up or simply stated that the meat was "processed."

Infrastructure and by-products

The only infrastructure or by-products mentioned was transportation. Twenty-seven percent of all students mentioned transportation.



*Students do NOT mention ranches or feedlots

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

Learning Progression

In general, high school students mentioned each step more often then middle school or elementary school students. This learning progression is evident as older students increasingly mentioned “package” (8.9%, 22.9%, 24.5%), “factory” (21.8%, 33.6%, 41.3%), “slaughterhouse” (4.8%, 19.3%, 24.5%), “farm” (41.4%, 50.7%, 55.9%), and cow (77.4%, 84.3%, 85.3%) more often than younger students (Figure 2). The difference between the proportion of high school and elementary school students who mentioned each step is statistically significant. In addition, 9.1% of all high school students mentioned “plants” in their supply chain, while only 3.2% of elementary and 2.9% of middle school students mentioned them.

There is a statistically significant association between the number of steps mentioned by students and school level ($\chi^2(4, N = 412) = 38.542, p < .001$). Elementary school students mentioned the fewest steps and high school students mentioned the most steps when tracing the supply chain. Thus, high school students give more detailed, in terms of listing more steps of the supply chain, than younger students.

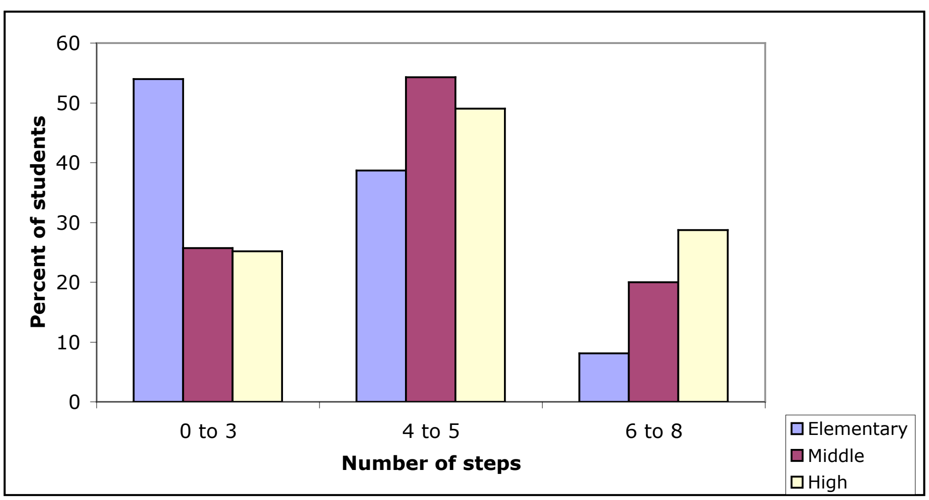


Figure 3. Number of steps mentioned by elementary, middle, and high school students for the hamburger supply chain.

Context

Rural students mentioned parents and growth more often than suburban and urban students. 22.31% of rural students mentioned parent, while 10.96% of suburban and 14.29% of urban students mentioned it; the differences in proportions are statistically significant ($p < 0.05$). Rural students mentioned growth significantly more often than suburban or urban students ($p < 0.05$). Interestingly, 16.43% of urban students mentioned "animal" or some type of animal other than a cow. Only 3.31% of rural students and 6.16% of suburban students mentioned "animal"; rural and suburban students specifically mentioned "cow" in their supply chains more often than urban students. There is no difference between the percentage of students who mentioned humans in their supply chain according to context. There is a statistically significant association between the number of steps mentioned by students and context ($\chi^2(4, N = 412) = 9.945$, $p < .05$). Rural students mentioned more steps than urban and suburban students. Overall, rural students seem to have more developed understandings of the hamburger supply chain than suburban or urban students.

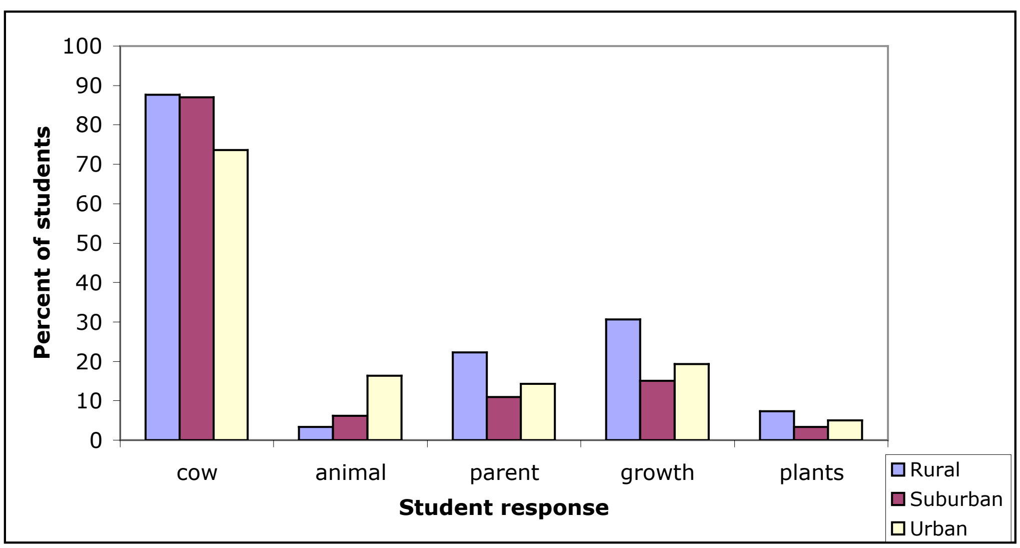


Figure 4. Percentage of rural, suburban, and urban students who mentioned steps of hamburger supply chain

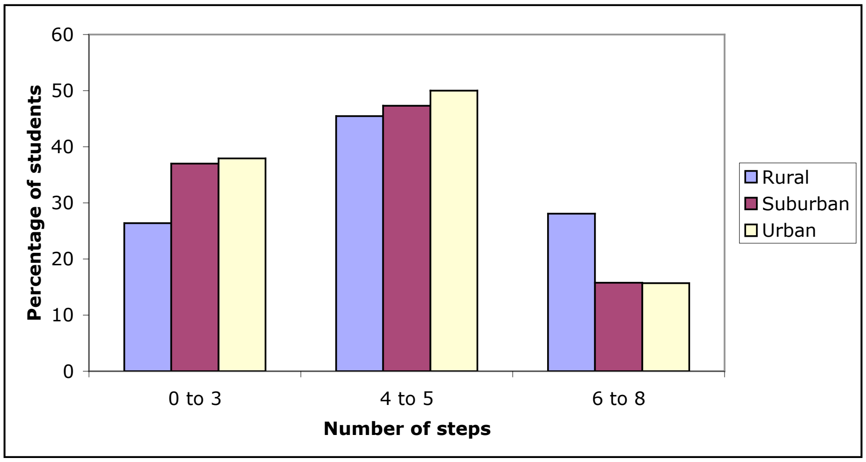


Figure 5. Number of steps in hamburger supply chain mentioned by rural, suburban, and urban students

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 examined the *actions and locations/places*, *transformation of matter*, and *infrastructure and by-products* that students mentioned in their responses. 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. Because students traced either the trash or recycling waste disposal chain, the percentage of students who mentioned a particular step was calculated according the waste disposal chain they traced. For example, when students mentioned landfill, the frequency of landfill was divided by the total number of students who traced the trash waste disposal chain (n=246) to find the percentage of students who mentioned landfill. A total of 246 students (60 elementary, 91 middle, 95 high school; 78 rural, 79 suburban, and 89 urban) traced the trash waste disposal chain. A total of 147 (52 elementary, 50 middle, and 45 high school; 40 rural, 62 suburban, and 45 urban) students traced the recycling waste disposal chain. Students who did not respond to part B of the question were not included as part of the total number of students tracing either the trash (n=246) or recycling waste disposal chain (n=147) in the percentage calculations for part B.

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. 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). 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) and context (rural, suburban, urban). 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

Table 2

Percentage of students' choice of waste disposal chain

Response	Elementary n=129*	Middle n=142*	High n=156*	Rural n=127*	Suburban n=149*	Urban n=151*	Total n=427*
Trash	51.9	54.2	50.6	51.2	47.4	57.6	52.2
Recycle	30.2	26.8	26.9	27.6	34.9	21.2	27.9
Combination	7.8	12	13.5	11.8	10.7	11.3	11.2
UI	2.3	0.7	1.3	1.6	0	2.6	1.4
NR	1.6	0.7	0	0	1.3	0.7	0.7
Other	6.2	5.6	7.7	7.9	5.4	6.6	6.6

*The sample sizes may be greater than the total number of students because a student's response may be coded as more than one code. For example, a student may have mentioned both trash and burn, which would be coded as trash and other.

For Part A of the question, most students, 52.2% of all students, said that they would throw the cup in the garbage (Table 2). Fewer students, 27.9%, stated that they would recycle the paper cup, or that they would either throw the cup in the garbage or recycle it (11.2%). 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. There is no significant difference between the proportion of elementary, middle, and high school students who responded either trash or recycle. While there is no significant difference in response according to grade level, there is a significant difference in the proportion of students who mentioned recycle according to context. A higher proportion of suburban students mentioned that they would recycle than urban students ($p < 0.005$), but there is no significant difference when comparing rural to suburban or rural to urban. There is not a significant difference in context for those who responded "trash."

Actors and Locations/Places

Similar to the hamburger supply chain, students generally depicted the paper cup waste disposal chain in terms of *locations/places*. Overall, when tracing the paper cup through the trash waste disposal chain, students commonly mentioned locations/places such as the trash can, coded as “trash” (79.3%), “dumpster” (24.0%), and “landfill” (52.8%) (Figures 6 and 7). When tracing the paper cup through the recycling waste disposal chain, students most commonly mentioned “recycling place,” the place where the cup was taken to be recycled (53.7%), “new product,” mentioned that the cup would be made into a new product (48.3%), and “recycling bin” (47.6%) (Figures 8 and 9).

Also similar to the hamburger supply chain, 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 in 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 students states, “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. 7.7% of students who traced the trash waste disposal chain mentioned a garbage man, or person who picks up the garbage to take it away. In contrast, of those who traced the recycling waste disposal chain, only 2.7% mentioned a recycling man, or person who picks up the recycling and transports it elsewhere. 8.2% of students who traced the recycling chain mentioned people buying a new product made from the recycled cup’s materials or reusing the paper cup.

Transformation of matter

Student descriptions of the transformation of matter were vague. When describing the trash waste disposal chain, 30.5% of all students stated that the paper cup would decompose and a relatively small percentage of students, 5.3% stated that the paper cup would be burned. In either case, students rarely gave more information about how the paper cup transformed, other than it decomposed or was burned. They occasionally mentioned that it returned back to the soil or ground. 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."

Infrastructure and by-products

The only infrastructure or by-products mentioned was transportation. Fifty-nine percent of all students mentioned transportation.

Learning Progression

In general, high school students painted a more detailed waste disposal chain than middle or elementary school students. In the trash waste disposal chain, for example, 70.0% of elementary, 78.0% of middle, and 86.3% of high school students mentioned that they would throw the paper cup in the "trash" (Figure 8). Similarly, 23.3% of elementary, 26.4% of middle, and 38.9% of high school students mentioned that the cup would "decompose," and 50.0% of elementary, 60.4% of middle, and 62.1% of high school students mentioned some form of "transportation," or movement of the cup from one location/place to another. In addition, similar to the hamburger supply chain, there is a statistically significant association between the number of steps mentioned by students and school level when depicting the trash waste disposal chain ($\chi^2(4, N = 248) = 15.206, p < .005$) (Table 3). Elementary school students mentioned the fewest steps and high school students mentioned the most steps when tracing supply and waste disposal chains. Thus, high school students give more detailed, in terms of listing more steps of the supply chain, than younger students.

There are more mixed results for students who depicted the recycling waste disposal chain. Middle school and high school students mentioned “recycling bin,” “recycling place,” and “new product,” more often than elementary school students. Middle school students mentioned “transportation” and some type of “processing” more significantly more often than high school students (in both cases, $p < 0.05$). High school students mentioned more steps in the recycling disposal chain than middle or elementary school students (Table 4).[3]

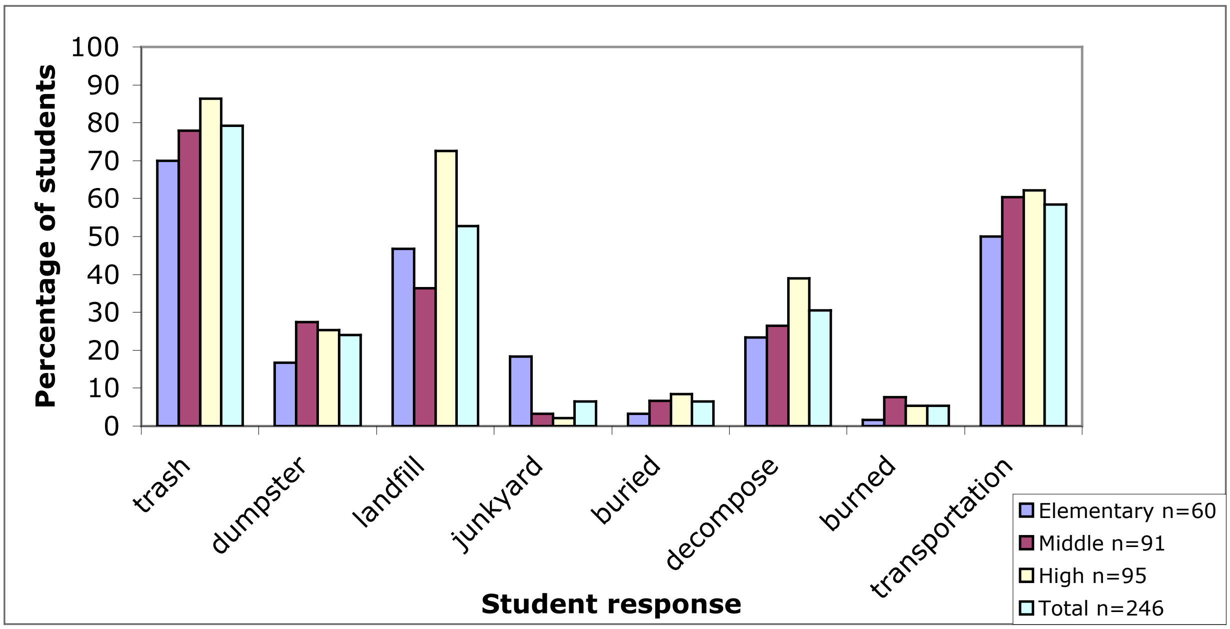


Figure 6. Percentage of students who mentioned steps of trash waste disposal chain

Table 3

Percentage of students who mentioned 0-2, 3-4, or 5-6 steps in the garbage waste disposal chain

Number of steps	**Level**			**Context**			**Total**
	Elementary n=61	Middle n=90	High n=97	Rural n=80	Suburban n=79	Urban n=89	Total n=248
0-2	39.3	32.2	16.5	25	21.5	36	27.8
3-4	57.4	53.3	67	52.5	64.6	61.8	59.7
5-6	3.3	14.4	16.5	22.5	13.9	2.2	12.5

[3] A chi square test of association could not be run because no elementary school mentioned 5 to 6 steps.

Table 4

Percentage of students who mentioned 0-2, 3-4, or 5-6 steps in the recycling waste disposal chain

Number of steps	**Level**			**Context**			**Total**
	Elementary n=44	Middle n=45	High n=37	Rural n=36	Suburban n=55	Urban n=35	Total n=136
0-2	61.4	24.4	32.4	44.4	34.5	42.9	39.7
3-4	38.6	51.1	54.1	36.1	54.5	48.6	47.6
5-6	0	24.4	13.5	19.4	10.9	8.6	12.7

Context

There is no clear trend when comparing responses from rural, urban, and suburban students for the paper cup waste disposal chain. When tracing the trash/garbage waste disposal chain, rural students mentioned “landfill,” that the cup “decomposes” or breaks down, and that the paper cup is “buried” more often than suburban and urban students. Suburban students mentioned “trash” (trash can), “dumpster,” and “transportation” more often than rural and urban students (Figure 7). 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.

For the recycling waste disposal chain, suburban students provided more detailed descriptions of the chain; they mentioned each step more often than rural and urban students. While a higher percentage of rural students mentioned *transportation, recycling bin, recycling place, separated/sorted, processed,* and *new product,* this percentage was only significantly different for *recycling place* (Figure 9). Thus, overall, there is not a significant different in students’ depictions of the recycling waste disposal chains according to context. In addition, there is not a statistically significant association between the number of steps mentioned by students and context when depicting the trash waste disposal chain.

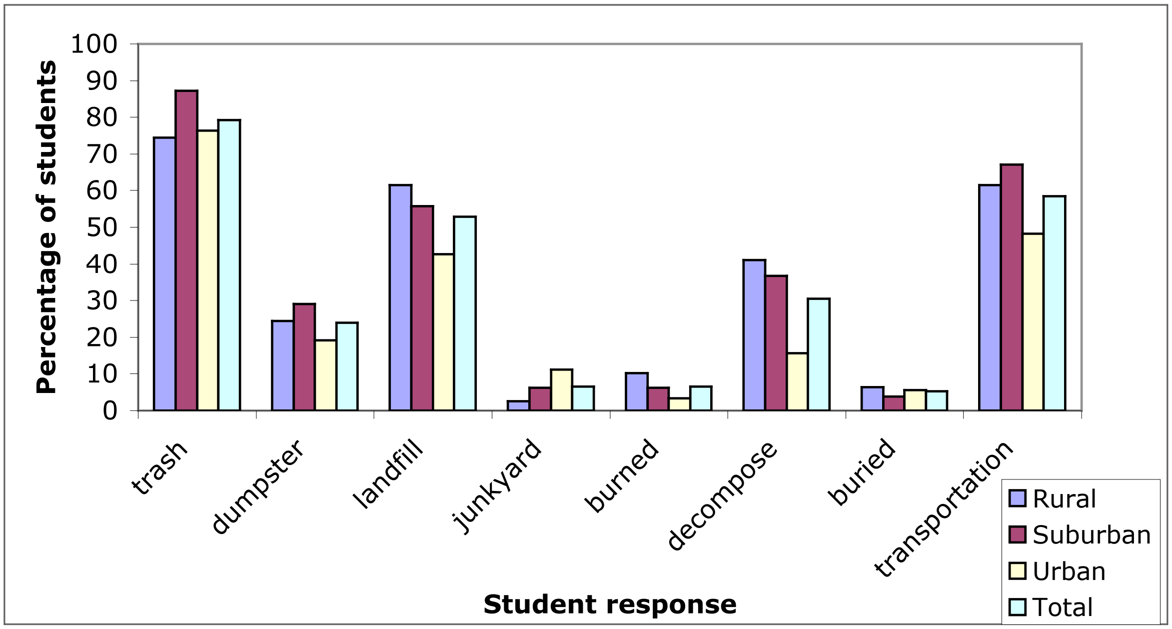


Figure 7. Percentage of rural, suburban, and urban students who mentioned steps of paper cup garbage waste disposal chain

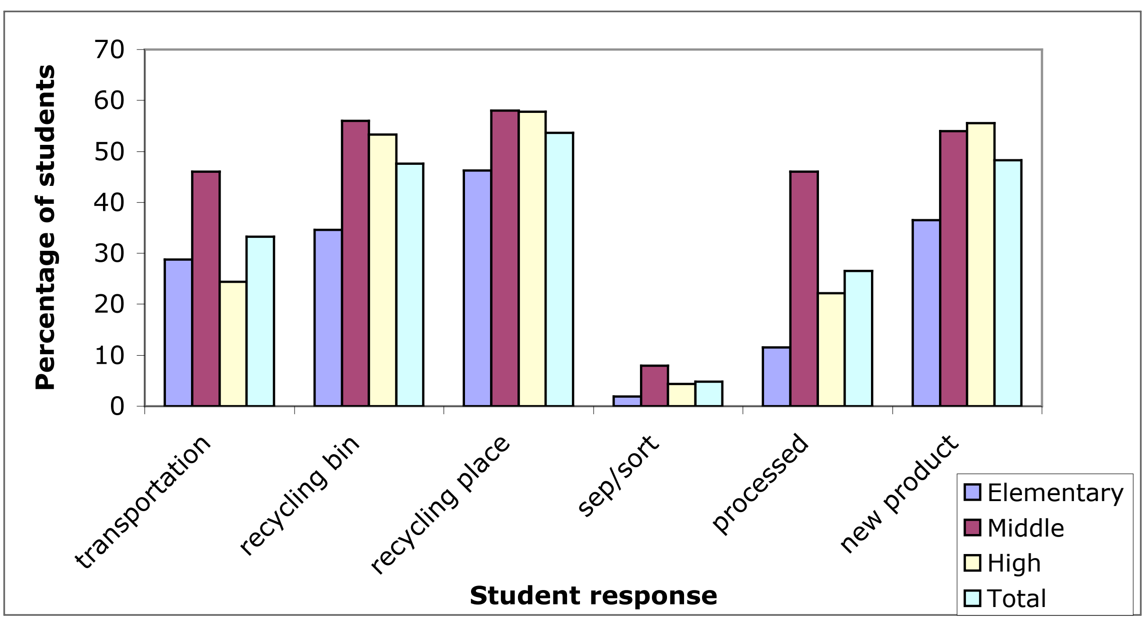


Figure 8. Percentage of elementary, middle, and high school students who mentioned steps of paper cup recycling waste disposal chain

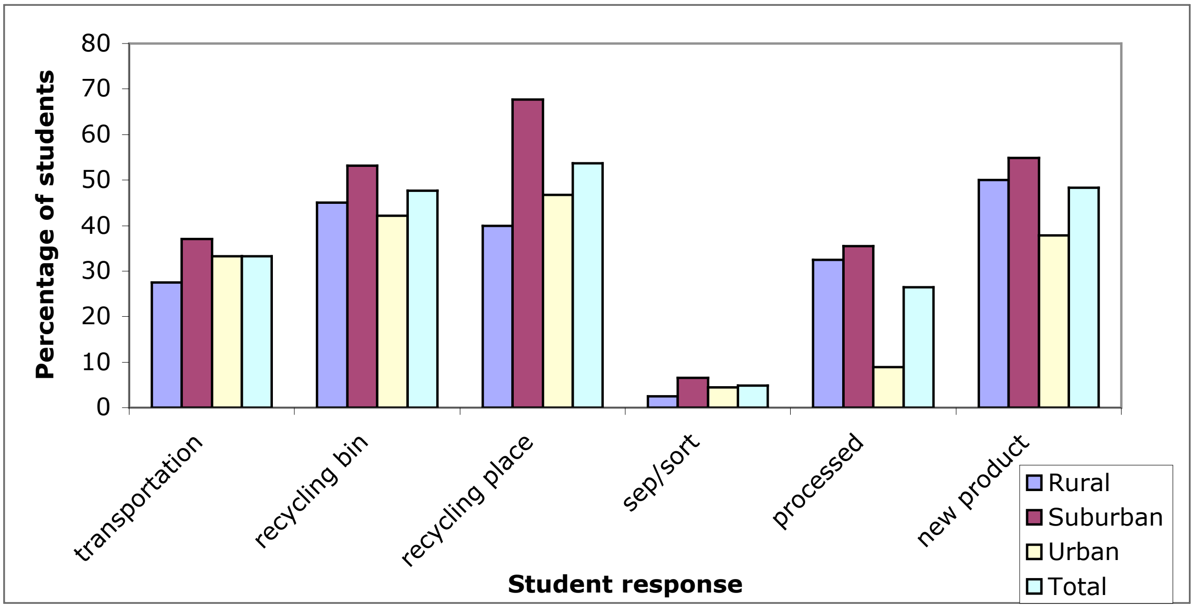


Figure 9. Percentage of rural, suburban, and urban students who mentioned steps of paper cup recycling waste disposal chain

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 part A of both questions, students were asked to circle yes or no. For part B of both 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 and rural, suburban, and urban students. For part B, some student responses may be coded for more than one code. 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).

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? Overall, 63.6% of the students circled ‘yes,’ signifying that there could be a connection and 34.5% circled ‘no’ (Table 5). While 63.6% of the aggregate sample mentioned that there could be a connection, only 51.2% of elementary school students respond yes, compared to 62.9% of middle school students and 74.8% of high school students. More suburban (70.5%) than rural (67.8%) than urban (53.1%) thought that there could be a connection between hamburger meat and a corn field.

Table 5

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

	School Level			**Context**			
	Elementary n=125	**Middle n=140**	**High n=147**	**Rural n=121**	**Suburban n=146**	**Urban n=145**	**Total n=412**
Yes	51.2	62.9	74.8	67.8	70.5	53.1	63.6
No	44.0	35.7	25.2	30.6	26.0	46.2	34.5
No Response	4.8	1.4	0.0	53.1	3.4	0.7	1.0

Transformation of Matter and Learning Progression

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, 29.1% 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 6). While 29.1% of all students said that cows eat corn, 12.8% of elementary, 27.9% of middle, and 44.2% of high school students gave this as their reason. A small percentage of all students, 2.2%, gave more detailed reasons, explaining *why* cows eat corn (1.6% of elementary, 0.7% of middle, and 4.1% of high school students). When elementary students thought that there could be a connection between hamburger meat and a corn field, they most often gave their reason as code C, the cows were on the same farm where the corn was grown (16.8%). 31.2% of elementary students thought that there was no connection because corn is not the same thing as hamburger meat. Thus, just as older students increasingly recognized that there could be a connection between hamburger meat and a corn field, older students give more detailed reasons as to how they are connected (i.e., older students more likely to trace the matter, code A and B).

Table 6

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

2A response	**Code**	**Characteristics of student answers**	**Level**			**Context**			**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

Yes/No	G	No response	4.8	1.4	2.7	2.5	2.7	3.4	2.9
Yes/No	H	UI	14.4	5.0	1.4	7.4	3.4	9.0	6.6
Yes/No	I	Other	16.0	21.4	16.3	15.7	15.1	22.8	18.0

Context

More suburban (70.5%) than rural (67.8%) than urban students (53.1%) thought that there could be a connection between hamburger meat and a corn field. While code B, cows eat corn, was the most common reason given for the connection, there is a significant difference between the proportion of urban students (16.6%) and the proportion of suburban (35.6%) and rural students (36.4%) that mentioned code B but this difference could be due to the fact that more urban students did not think there was a connection.

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 63.6% 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 (93.4%) (Table 7). More elementary (8.0%) than middle, (7.1%), then high school students (4.1%) did not think that there could be a connection, but this difference in proportions is not significantly different. 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 ($p < 0.05$). The test between rural and urban students could not be conducted because the sample size requirements for rural students did not meet the sample size requirement, n(1-p) must both be equal to or greater than 5.

Table 7

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

	Level			Context			
	Elem. n=125	**Middle n=140**	**High n=147**	**Rural n=121**	**Suburban n=146**	**Urban n=145**	**Total n=412**
Yes	92.0	92.1	95.9	95.9	95.2	**89.7**	93.4
No	8.0	7.1	4.1	4.1	4.1	10.3	6.3
No Response	0.0	0.7	0.0	0.0	0.7	0.0	0.2

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 8

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

2A response	**Code**	**Characteristics of student answers**	**Level**			**Context**			**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
Yes/No	F	No response	0.8	0.0	0.7	4.1	2.7	6.9	4.6
Yes/No	G	UI	5.6	6.5	2.0	4.1	2.7	6.9	4.6
Yes/No	H	Other	12.0	6.5	8.1	7.4	11.0	7.6	8.7

*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.

Transformation of matter and Learning Progression

Overall, 93.4% of all students thought that there could be a connection because paper is made from trees (Table 8). The most common reason for the connection between a paper cup and a tree was code C, paper is made from trees (73.3%). Some students gave a more detailed answers: they specifically mentioned that paper is made from *wood*, code B, or that is it made from *pulp* or undergoes some *process* in order to be transformed into paper, code A. While we are unable to test the statistical significance,[4] more high school (8.1%) than middle (5.0%) than elementary school students (0.8%) mentioned pulp or some type of process, code A, when describing the connection between a paper cup and a tree.

Context

While we are unable to test the statistical significance, a higher percentage of suburban (6.8%) than rural (5.8%) than urban (2.1%) students mentioned pulp or some type of process, code A, when describing the connection between a paper cup and a tree.

Washing Dishes

Handwashing and Dishwasher Question

In this 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?" They were then asked to fill out a table, listing the resources used when washing dishes by each method, handwashing and using a dishwasher, and the impact that using these resources has on the environment. While the hamburger meat question asked students to specifically trace the supply chain of the hamburger

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[4] Both samples must satisfy the standard binomial requirement that n(p) and n(1—p) must both be equal to or greater than 5.

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 generate 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. Frequency counts were obtained and student response percentages calculated overall, and separately for elementary, middle, and high school students and rural, suburban, and urban students. Percentages were calculated by taking the frequency of a resource and dividing it by the total number of elementary, middle, and high school students or rural, suburban and urban students. For example, the percentage of elementary students who mentioned water as a resource used when handwashing dishes was calculated by taking the frequency of elementary school students who mentioned soap (102) and dividing it by the total number of elementary school students who took the assessment (125) for a percentage of 81.6%.

For impact of resource on the environment, emergent codes were developed from a sample of student responses. The impact of resources was coded in terms of supply and waste disposal chains (See Table 10). A student response could be coded as more than one code. For example, student may state that the impact of using electricity when using a dishwasher is that there less electricity and it pollutes the environment. This would be coded both as A and D (see Table 11 for explanations of the codes). Frequency counts were obtained and student response percentages calculated overall, and separately for elementary, middle, and high school students and rural, suburban, and urban students. Percentages were calculated by taking the frequency of a code and dividing it by the number of students who mentioned the particular resource. For example, the percentage of elementary school students who mentioned the impact of using water for handwashing dishes as there being “less” water, code A, was calculated by taking the number of students whose responses were coded as A (19), and dividing that by the total number of elementary school students who mentioned water as a resource (87). Thus, the percentage of elementary students who stated that there would be “less” water was 21.8%.

One-tailed significance of the difference between two independent proportions tests were conducted to determine the significance between student responses to dishwashing versus handwashing and between students answers by level (elementary, middle, and high school) and context (rural, suburban, and urban).

Results

Overall, the resources most often mentioned by students as resources used in both hand washing and using a dishwasher to wash dishes were soap and water (Table 9). Students mentioned soap as a resource significantly more often when handwashing dishes 79.1%) than when using a dishwasher (67.0%) ($p < 0.001$). They also mentioned water significantly more often when handwashing dishes (75.0%) than using a dishwasher (60.4%) ($p < 0.0001$). 39.1% of all students mentioned electricity as a resource used when using a dishwasher, but only 2.2% of all students mentioned it when washing dishes by hand, which is also a statistically significant difference ($p < 0.0001$). 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.

Learning Progression

There are no clear trends for resources listed amongst students according to level for soap. A statistically significantly higher proportion of high school students than middle or elementary school students mentioned water as a resource for both handwashing and using a dishwasher to wash dishes (Table 9). Additionally, while 39.1% of all students mentioned electricity as a resource used when dishwashing, 34.4% of elementary, 39.3% of middle, and 42.9% of high school students mentioned it. 0.8% of elementary, 1.4% of middle, and 4.1% of high school students mentioned the use of electricity when handwashing dishes, but neither trend is statistically significant.

Table 9

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

	Elementary		**Middle**		**High**		**Total**	
Resource	HW n=125	DW n=125	HW n=140	DW n=140	HW n=147	DW n=147	HW n=412	DW n=412
Soap	81.6	67.2	79.3	65.7	76.9	68.0	79.1	67.0
Water	69.6	52.8	72.1	55.7	82.3	71.4	75.0	60.4
Sponge	28.8	0.8	25.7	2.1	21.8	0.7	25.2	1.2
Towel	34.4	1.6	42.1	5.0	31.3	2.0	35.9	2.9
Electricity	0.8	34.4	1.4	39.3	4.1	42.9	2.2	39.1

**HW = handwashing, DW = dishwasher*

Context

There are no clear trends for resources listed among students according to context (Table 10).

Table 10

Percentage of rural, suburban, and urban students who mentioned various resources used when handwashing or using a dishwasher to wash dishes

	Rural		Suburban		Urban		Total	
Resource	HW n=121	DW n=121	HW n=146	DW n=146	HW n=145	DW n=145	HW n=412	DW n=412
Soap	74.4	62.0	84.2	70.5	77.9	67.6	79.1	67.0
Water	70.2	56.2	79.5	67.1	74.5	57.2	75.0	60.4
Sponge	18.2	0.0	35.6	1.4	20.7	2.1	25.2	1.2
Towel	33.9	3.3	25.3	2.1	48.3	3.4	35.9	2.9
Electricity	0.0	38.0	4.8	39.0	1.4	40.0	2.2	39.1

**HW = handwashing, DW = dishwasher*

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

Table 11

Explanation of codes for impact of resources on the environment

Code	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	Student wrote that there would be “no impact” or “none”
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.	

Table 12

Percentage of elementary, middle and high school students who mentioned various impacts of using resources when handwashing or using a dishwasher to wash dishes

	Elementary		**Middle**		**High**		**Total**	
Soap	HW	DW	HW	DW	HW	DW	HW	DW
A	4.9	3.6	9.0	7.6	0.0	1.0	4.6	4.0
B	2.9	1.2	2.7	2.2	4.4	3.0	3.4	2.2
C	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
D	12.7	11.9	26.1	23.9	26.5	31.0	22.1	22.8
E	11.8	13.1	8.1	7.6	11.5	9.0	10.4	9.8
F	12.7	10.7	7.2	5.4	8.8	5.0	9.5	6.9
G	33.3	34.5	28.8	31.5	29.2	29.0	30.4	31.5
H	14.7	21.4	8.1	8.7	14.2	17.0	12.3	15.6
I	6.9	3.6	9.9	14.1	5.3	6.0	7.4	8.0

*This table represents the results for one resource: soup. Due to space issues, tables for each resource are not included. Please contact the first author for the data for the other resources.

Overall, 22.1% of the students who mentioned soap as a resource used in handwashing dishes and 22.8% of those who mentioned it for using a dishwasher said that soap impacts the environment because it polluted or harmed animals, plants, or water, code D (Table 12). For example, one student wrote that soap "kills plants." 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.

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, 34.3% of all students mentioned that using water means there is less water available and 30.9% of students gave the same reason when using a dishwasher (code A). Similar to water, the most common answer students gave for the impact of electricity from using a dishwasher on the environment was that there was less of it, code A (21.2%). Students who connect the impact on the environment to the supply chain recognize that we are taking resources from the natural environment.

Of the 28.3% of students who mentioned sponge as a resource used when handwashing dishes, the impact on the environment was fairly evenly distributed among codes A, less sponges available (4.8%); B, mentioned materials used to make sponge (8.7%); D, the sponge pollutes something else such as water (7.7%); E, no impact (11.5%); and F, don't know (9.6%). 40.2% of all students mentioned a towel as a resource used when handwashing dishes. Students most commonly mentioned the impact of a towel on the environment was code B, from "using stuff to make it (12.2%) or stated that the towel had "no impact" on the environment, code E (12.8%).

Learning Progression

Overall, there were very minimal trends in student answers across grade level. A higher percentage of middle and high school student responses related to supply and waste disposal chains, codes A, B, C, or D, than elementary school students. For example, 20.6% of elementary, 37.8% of middle, and 31.0% of high school student responses were coded as A, B, C, or D for when soap is used to hand wash dishes. Similarly, 29.95 of elementary, 55.4% of middle, and 48.8% of high school student responses were coded as A, B, C, or D for when water is used as a resource of hand wash dishes. But when the supply and waste disposal chain codes (codes A-D) were disaggregated, there did not appear to be a trend across level.

Context

Overall, there were slight trends in student answers across context. Suburban student responses more frequently related to supply and waste disposal chains than rural or urban students. When using soap to hand wash dishes, 37.4% of suburban, 30.0% of rural, and 15.9% of urban student responses related to supply or waste disposal chains (Table 13). The proportion of rural and suburban students who responded in this manner was significantly higher than urban students. The same trend applies for student answers regarding using soap when using a dishwasher, and when using water in both handwashing and using a dishwasher. When using a sponge or towel when handwashing dishes, suburban student responses more frequently related to supply and waste disposal chains than rural or urban students, but the numbers were too low to determine if the difference was statistically significant. For electricity, suburban student response more frequently related to supply and waste disposal chains, but it was only significantly higher than the proportion of rural student who responded in the same manner.

Table 13

The percentage of students who mentioned codes A-D, codes relating to supply and waste disposal chain, as an impact of using various resources on the environment

	Rural		**Suburban**		**Urban**	
Resource impact*	**HW**	**DW**	**HW**	**DW**	**HW**	**DW**
Soap	30.0	34.78	37.4	39.8	15.9	13.3
Water	42.4	35.3	61.2	612	31.5	26.5
Sponge	22.7	0.0	54.5	0.0	22.7	0.0
Towel	19.5	0.0	29.7	0.0	12.9	0.0
Electricity	0.0	28.3	57.1	50.9	0.0	37.9

*Students responses when asked what impact using a resource has on the environment that are related to supply chains and/or waste disposal chains (aggregate of codes A-D)

**HW stands for handwashing; DW stands for using a dishwasher

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 mentioned electricity less often. When students did mention electricity, 39.1% of all students mentioned it as a resource used by a dishwasher, but only 2.2% of the time when handwashing dishes even though electricity is used in both handwashing and using a dishwasher to wash dishes. 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. High school and middle school student responses were more often related to supply and waste disposal chains elementary school student responses. In addition, suburban student responses were more often related to supply and waste disposal chains than rural or urban students.

Awareness or knowledge of major environmental issues

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 part A, student responses were coded as yes, no or no response. For parts B and C, only students who responded yes to part A were coded for parts B and C. For parts B and C, student responses could be coded for more than one code. Frequency counts were obtained and student response percentages calculated overall, and separately for elementary, middle, and high school students and rural, suburban, and urban students for parts A, B, and C of this question. Chi-squared tests of association were run to determine if there were significant associations between student responses according to grade level or context for part A. For parts B and C, significance of the difference between two proportions tests were conducted to determine any significant differences between level or context.

Results

For part A, Have you ever heard of global warming (also called global climate change)?, 79.4% of all students have heard of global warming (Figures 10a and 10b). While 79.4% of all students have heard of global warming, 68.8% of elementary, 73.6% of middle, and 94.2% of high school students responded that they have heard of it. There was a significant association between student responses and grade level ($p < 0.05$). 93.2% of suburban, 75.2% of rural and 69% of urban students have heard of global warming. The association between student response and context is also significant ($p < 0.05$).

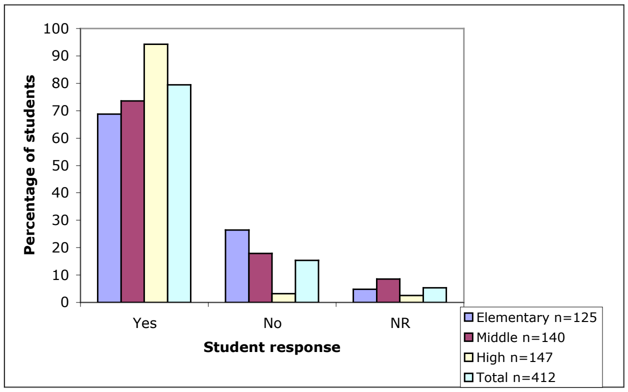

Figure 10a. Percentage of elementary, middle and high school student responses to awareness of global warming.

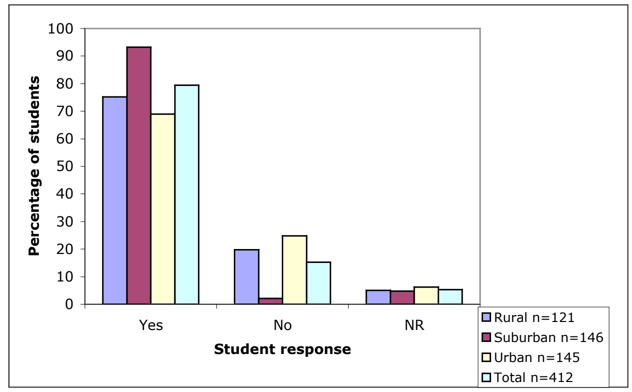

Figure 10b. Percentage of rural, suburban, and urban student responses to awareness of global warming.

Table 14

Percentage of student responses for cause of 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**
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
Other*	16.3	13.6	13.0	16.5	11.0	16.0	14.1
Unintelligible	7.0	4.9	4.3	2.2	4.4	9.0	5.2
No response	4.7	1.0	0.7	0.0	4.4	0.0	0.0

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.*

For part B, What do you think 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 14). Student responses were coded as “fossil fuels” when they mentioned carbon dioxide, fossil fuels, or greenhouses gases. Responses were coded as “pollution” when they mentioned pollution in general, without naming a specific source of pollution or by-product such as cars, factories, or fossil fuels. For example, one student stated, “Pollution in the air gets into the atmosphere and adds extra insulation to the earth, making it warmer.” 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.”

Learning Progression

Overall, there do not appear to be trends across grade level.

Context

While there did not appear to be trends across grade level regarding the cause of global warming, there were some trends across context. 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 “ozone,” a depletion in the ozone layer, 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.[5] 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

[5] Test of significant 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.

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.

Part C asked students, how do you think global warming/global climate change can be reduced? The highest percentage of all students, 22.9%, mention that it can be reduced by some means related to cars, such as driving less or using alternatively powered cars (Table 15). 15.6% of all students mentioned that global warming could be reduced by “reducing pollution.” These student responses did not specifically mention what type of pollution needs to be reduced or how pollution can be reduced. Only 8.6% of all students mentioned reducing fossil fuels, which is the same percentage of students who stated that they “didn’t know” how global warming could be reduced.

Table 15

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

Other*	20.9	24.3	38.4	31.9	21.3	38.0	29.4
Unintelligible	10.5	9.7	3.6	8.8	4.4	10.0	7.3
No response	12.8	5.8	3.6	5.5	5.9	9.0	6.7

**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.*

Learning Progression

While 22.1% of elementary, 7.8% of middle, and 26.8% of high school students mentioned fossil fuel as a cause of global warming, only 7.0% of elementary, 1.9% of middle, and 14.5% of high school students mentioned that global warming could be reduced by reducing fossil fuel emissions (Table 14). Significantly more high school students mentioned reducing fossil fuels than elementary ($p < 0.05$) and they also mentioned it more often than middle school students.[6] More middle and high school students mentioned "reduce pollution" than elementary school students.[7] 15.1% of elementary, 23.3% of middle, and 27.5% of high school students mentioned "drive less" referring to driving cars less and high school students mentioned it significantly more often than elementary school students ($p < 0.05$). More elementary, than middle, than high school students stated that they did not know how to reduce global warming or did not respond to the question. Elementary school students responded these ways statistically significantly more often than middle or high school students ($p < 0.05$).

Context

While the results are not statistically significant, suburban students mentioned "reduce fossil fuels" more often (12.5%) than rural (8.8%) than urban (3.0%) students. Suburban students also mentioned "drive less" and "alternative energy," which included answers such as solar

[6] Test of significant could not be run because the middle school sample did not satisfy the standard binomial requirement that n(p) and n(1—p) must both be equal to or greater than 5.
[7] Test of significant could not be run because the elementary school sample did not satisfy the standard binomial requirement that n(p) and n(1—p) must both be equal to or greater than 5.

panels, wind, or hydrogen energy sources, significantly more often than rural or urban students.[8] In addition, they less often mentioned that global warming "can't be reduced." Suburban students exhibited a better understanding of possible ways global warming can be reduced.

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. But there does not appear to be any trend across grade level regarding the causes of global warming. Most students hold 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. Although there does not appear to be any trend regarding *causes* of global warming, older students progressively demonstrate a better understanding of ways to *reduce* global warming. For example, more high school (14.5%) than middle (1.9%) or elementary (7.0%) school students mentioned reducing fossil fuels.

There were trends across context in student responses to the causes of and ways to reduce global warming. Overall, suburban students seem to hold a better understanding of both. Suburban students more often mentioned "fossil fuels" as a cause and "reduce fossil fuels." It seems logical that since more suburban students mentioned "fossil fuels" as a cause that they would also mention it as a way to reduce global warming. Rural students more often mentioned "aerosols" and rural and urban students more often gave "weather" as a cause of global warming. Suburban students mentioned "drive less" and "alternative energy" as ways to reduce global warming more often than rural and urban students. Suburban students also stated that global warming "can't be reduced" less often. Thus, suburban students demonstrate a better

[8] All comparisons were statistically significant ($p < 0.05$) except for urban for the "alternative energy" code. Test of significant could not be run because the urban sample for this code did not satisfy the standard binomial requirement that $n(p)$ and $n(1—p)$ must both be equal to or greater than 5.

understanding of both the causes of and ways to reduce global warming than rural and urban students.

Forest Preservation Question

This question asked students, “Why do you think it might be important to preserve our forests?” We were interested in why students might think forests are important and whether students understand the role that forests plays in ecosystems.

Data Analysis Procedure

Emergent codes were generated from a sample of student responses. A student response could be coded as more than one code. For example, a student might state that it is important to preserve forests because it provides humans with oxygen to live and homes for animals. This response would be coded for both “human oxygen” and “animal habitat” (see Table 16). Frequency counts were obtained and student response percentages calculated overall, and separately for elementary, middle, and high school students and rural, suburban, and urban students.

Results

Fifty-two percent of all students stated that it is important to preserve forests because they have some value to humans (i.e., oxygen, food, materials) and 41.6% mentioned that there is some value to animals (i.e., habitat, biodiversity, food) (Table 16). Only 13.1% of all students mentioned forests’ value in relation to something at the ecosystem level, such as their importance in reducing carbon or pollution, 4.1% mentioned the importance for plants, and 6.3% mentioned the intrinsic value of forests (e.g., aesthetics).

Students most often mentioned that it was important to preserve forests because they provide “oxygen” or air for humans to breathe (27.4%). Some students mentioned more generally that oxygen is important without specifying who or what oxygen is important for. These answers were coded under the "oxygen general" category. When aggregated, 43.9% of all students mentioned that oxygen was an important reason to preserve forests. The next most common answer was animal "habitat" (25.5%).

Learning Progression

Progressively more high school (51.7%) than middle (42.1%) than elementary (36.8%) school students mentioned either "oxygen general" or human "oxygen" as a reason to preserve forests. The difference in proportions between high school and elementary students is statistically significant ($p < 0.05$). Significantly more high schools students (20.4%) mentioned the importance of forests relating to issues at the ecosystem level than either middle school (9.3%) or elementary school students (8.8%) ($p < 0.05$).[9]

Context

51.4% of suburban, 44.6% of rural, and 35.4% of urban students mentioned "oxygen general" or human "oxygen" as a reason to preserve forests, and the difference between the proportion of suburban and urban students is statistically significant.[10] There appears to be a slight trend in the percentage of students who mentioned "intrinsic" – 8.9% of suburban, 6.1% of urban, and 3.4% of rural students - although the percentage of students who mentioned some type of intrinsic value such as "beauty of environment" was small. Significantly more suburban (54.8%) than rural (41.3%) or urban (40.8%) students mentioned that it was important to preserve forests because of some value to animal ($p < 0.05$). Overall, suburban students more

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[9] While there was a statistically significant difference between high school and middle school students and high school and elementary school students ($p < 0.05$), there was not a statistically significant difference between elementary and middle school students.

[10] While there was a statistically significant difference between suburban and urban students ($p < 0.05$), there was not a statistically significant difference between suburban and rural or rural and urban students.

often mention the importance of preserving forests as relating to oxygen, animals, the ecosystem, or intrinsic value than rural or urban students.

Table 16

Percentage of student responses to why we should preserve our forests

Response	Elementary n=125	Middle n=140	High n=147	Rural n=121	Suburban n=146	Urban n=147	Total n=412
oxygen general	11.2	19.3	18.4	14.9	25.3	8.8	16.5
Human							
oxygen (h)	25.6	22.9	33.3	29.8	26.0	26.5	27.4
food (h)	0.8	5.0	6.8	4.1	3.4	5.4	4.4
materials (h)	8.8	13.6	12.2	6.6	13.7	13.6	11.7
other (h)	8.0	7.9	8.8	12.4	5.5	7.5	8.3
Total	**43.2**	**49.3**	**61.2**	**52.9**	**48.6**	**53.1**	**51.7**
Animals							
habitat	28.0	18.6	29.9	22.3	32.2	21.1	25.5
biodiversity	8.8	7.1	12.2	9.1	12.3	6.8	9.5
food	0.8	2.1	2.0	1.7	1.4	2.0	1.7
other	8.8	9.3	10.2	8.3	8.9	10.9	9.5
Total	**46.4**	**37.1**	**54.4**	**41.3**	**54.8**	**40.8**	**46.1**
Plants	3.2	2.9	6.1	5.0	3.4	4.1	4.1
Intrinsic Value	6.4	6.4	6.1	3.3	8.9	6.1	6.3
Ecosystem level							
reduce carbon/pollution	6.4	7.1	15.6	9.1	15.8	4.8	10.0
global warming	2.4	1.4	3.4	1.7	2.7	2.7	2.4
ozone depletion	0.0	0.7	1.4	1.7	0.0	0.7	0.7
Total	**8.8**	**9.3**	**20.4**	**12.4**	**18.5**	**8.2**	**13.1**
Other	8.0	10.0	15.0	7.4	12.3	12.9	11.2
Unintelligible	8.0	9.3	0.7	4.1	4.8	8.2	5.8
No response	8.8	16.4	6.1	9.1	6.8	15.0	10.4

Discussion of Forest Preservation Results

Students most commonly state that it is important to preserve our forests because they are an important source of oxygen. Students also most often state the reason to preserve our forests in terms of human needs – human need for oxygen to survive, food to eat, or materials such as wood or medicines. Older students and suburban students more often mention that it is important to preserve our forests because they have value to the ecosystem such as reducing the amount of carbon dioxide or reducing global warming (which is similar, but the students did not specifically mention carbon dioxide). In addition, suburban students also mention values to animals and an "intrinsic value" more often than rural or urban students.

Discussion

Student understanding of supply and waste disposal chains and environmental problems lead to two interesting ideas about student understandings: 1) Students' understanding of how we are dependent on natural systems; and 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? and 2) What awareness do students show of the human actions that have the greatest environmental impact?

First, we 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:

- *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 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?
- *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?

It is important for students to understand these themes in order to have a complete picture of supply and waste disposal chains. 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, most students traced the hamburger meat back to the cow or some type of animal, almost half of all students mentioned a farm where the cow lives, and some recognized the life cycle of animals (i.e., growth) (see

Figure 2). Thus, most students connected the human engineered food production system (beef) with the natural system (living animals). When students were asked if there could be any connection between hamburger meat and a corn field, more than half of all students circled ‘yes’ and students most commonly gave the reason for the connection as “cows eat corn” (code B, see Table 5). Yet most students did not include corn or plants that the cows eat in order to grow in their depictions of the hamburger supply chain.

When students were asked if there could be a connection between a paper cup and a tree, most 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). 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. In this case, the paper cup did not reenter a natural system.[11]

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. But 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

[11] While students did not mention waste reentering a natural system, the waste and by-products from the recycling process does reenter natural systems.

natural and human engineered) involved with each step and how they are connected to each other through infrastructure.

Actors/locations/places

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," 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.

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. 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 some students did. Students did mention humans in the question that asked students why it might be important to preserve forests. 51.7% of all students mentioned that it is important to preserve forests because of its importance to humans (i.e., provides us with oxygen, materials). 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. In future work, it will be important to ask students how humans play a role in supply and waste disposal chains.

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. They must also understand 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 significantly less often than they mentioned locations or places when depicting supply and waste disposal chains. 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).

Transformation of matter and energy

We believe that students need to know the actors and locations/places involved in supply and waste disposal chains, the infrastructure that supports the chains, and how matter and energy is transformed within the chains. 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. When they did mention energy, they more often mentioned it as a resource used by a dishwasher (39.1%) to wash dishes. They rarely mentioned it as a resource used when handwashing dishes (2.2%), even though energy is needed to heat water when handwashing dishes.

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%). About a quarter of all students mentioned that the cup was processed and almost half of students stated that the cup was made into a new product when depicting the recycling waste disposal chain. But again, they were vague – they simply stated that the cup was “processed” or “made into new product.” 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 only 4.9% of all students mentioned some type of process that the tree undergoes to be made into paper. Overall, the transformation of matter appears to be a 'black box' to students.

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, much of the negative impact on the environment comes from feedlots, which no students mentioned in their depictions of the chain. Feedlots are where cattle consume large amounts of corn and where large amounts of waste are produced (i.e., by-products). 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. When Pollan (2002) decided to follow the path of one cow from the "farm" to its slaughtering, he traced the corn used to feed the cattle from a particular feedlot back to the fields where it grows and found a million-acre crop that consumes much chemical herbicide and fertilizer. The nitrogen runoff from the corn crop travels down the Mississippi River into the Gulf of Mexico, where it created a 12,000 square-mile dead zone. According to a Cornell ecologist who specializes in agriculture and energy, Pollan's one cow was responsible for the consumption of approximately 284 gallons of oil during his lifetime. In addition, feedlots and Concentrated Animal Feeding Operations (CAFOs) produce massive amounts of waste that can get into our water systems, which can then end up in our drinking water or the food that we eat from rivers, streams, and lakes. The pollution can end up killing off animals and plants (Woiwode & Henning, 2005; see also The Report of the EPA/State Feedlot workgroup, United States Office of Wastewater Enforcement, Environmental Protection and

Compliance Agency Washington, DC September 1993). 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 because of their consumption of resources and by-products created.

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 wouldn’t decompose back into soil) or what happens at recycling centers (they know that the cup gets turned into a new product). In the handwashing/dishwasher question, students mentioned resources used to wash dishes such as water, soap, and towels. Some resources, such as energy appear to be “invisible” to students. 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. When students did recognize some impact using water or energy has on the environment when using a dishwasher, they most often stated that there would be “less” water or energy. They rarely connected the use of water or energy to the waste disposal chain (e.g., pollution of water or air). When students did recognize an impact on the environment, they connected the impact to either the supply chain or waste disposal chain, but not both. Some parts of supply and waste disposal chains may be more visible to students than others. But even in the parts that are visible to students, they demonstrated limited understanding

It is understandable that students may not know what goes on at landfills and recycling centers. Students may not have any experiences with either; they may not have learned about them inside or outside of school. They also may not be familiar with how the soap and towels they use are made or where energy comes from. Certain steps of supply and waste disposal chain may be invisible or unknown, and even entire supply and waste disposal chains may be ‘black boxes.’ It is important to recognize the gaps in student understanding of supply and waste disposal chains. When students do not recognize steps or understand the processes that occur in these locations/places (i.e., how the matter is transformed and the by-products created), they cannot understand the impact that these processes have on the natural environment.

It is important to note some of the limitations of the assessments, which will be further discussed in the *Limitations and future directions section*. Students do not typically trace matter and energy through supply and waste disposal chains in science classes. They may know more about the steps of supply and waste disposal chains than we could ascertain from paper and pencil assessments. Because the nature of the questions was most likely unfamiliar to students (e.g., type of question, table format), students may provide more detailed responses through interviews. The dishwashing question may have been difficult for students to understand, especially for elementary school students. Some students may not understand what “resources” are and what “impact on the environment” means. In future studies, we may gain more information by interviewing students to determine if they understand where various resources (i.e., water, food, wood) come from and what happens to them after we use them. But overall, these supply and waste disposal questions suggest that students need to be able to understand where resources and services come from and where they end up, the locations/places and actors they travel through, the infrastructure and by-products that connect them and how the resources and services are transformed in order to understand the impact that human actions have on the natural environment. Furthermore, 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. This will be discussed further in the *Implications for science teaching and curriculum section.*

Learning Progression

There are trends in student knowledge from elementary to high school. Overall, high school students have a more developed understanding and awareness of supply and waste disposal chains and major environmental issues. 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. The number of steps mentioned in supply and waste disposal chains is significantly associated with school level; elementary school students mentioned the fewest steps and high school students mentioned the most steps when tracing supply and waste disposal chains. In other words, older students mentioned more *actors and locations/places* than younger students. 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. In other words, older students recognized some type of *transformation of matter and energy* more often than younger students.

In regards to environmental problems, more high school than middle or elementary school students have heard of global warming. 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. 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. Another way to view global warming is in terms of *infrastructure and by-products*. Much of global warming is attributed to the burning of fossil fuels. For example, vehicles (i.e., infrastructure) that transport resources and services to and away from us burn fossil fuels. Burning fossil fuels release greenhouse gases into the environment (i.e., by-products). Thus, older students may be more aware of *infrastructure and by-products* than younger students.

Also, in general high school students mentioned various reasons for preserving forests such as oxygen, value to animals, value to the ecosystem and intrinsic value more often than elementary or middle school students. They appear to be more aware of forest ecosystems. Overall, older students more often recognize *actors and places/locations, transformation of matter and energy*, and *infrastructure and by-products*. It makes sense that older students would have more detailed understandings of supply and waste disposal chains and environmental problems. Older students have had more experiences both in school and outside of school that they can draw on to understand these concepts.

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; they mentioned parents and growth more often than suburban and urban students. Also, rural students mentioned more steps in the hamburger supply chain than suburban or urban students. There is no difference between the percentages of students who mentioned humans in their supply chain according to context. While rural students exhibited more detailed knowledge about the supply chain, suburban students mentioned more steps in the waste disposal chain than rural or urban students. 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.

There are also some trends in student knowledge of environmental problems 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. When asked why it is important to preserve our forests, suburban students mentioned values to animals, ecosystems, and intrinsic value more often than rural or urban students. In general, suburban students seem to demonstrate a more developed knowledge of supply and waste disposal chains and environmental issues, but there do not appear to be clear trends across the questions analyzed as to which themes of supply and waste disposal chains (actors and locations/places, transformation of matter and energy, infrastructure and by-products) are more visible or less visible due to context. However, it does seem that certain aspects of various supply and waste disposal chains and environmental issues may be more visible to older students and students from different contexts.

Summary of Discussion

Overall, results indicate that students' scientific accounts are incomplete (practice 2). As explicated in the *Connections between human and natural systems section,* in both supply and waste disposal chains, students mentioned energy, infrastructure, and by-products less often than locations/places. Many parts of supply and waste disposal chains are invisible to students. For the parts of supply and waste disposal chains that students did mention, they appear to hold vague understandings of them. For example, 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. Students also held incorrect or incomplete knowledge about the causes of global warming. For example, they often stated the ozone, aerosols, or the sun causes global warming.

In the dishwashing question, students had to apply their knowledge of human engineered and environmental systems when thinking about the resources used and the impact of using those resources when washing dishes (practice 3). Students had a difficult time describing the impact of resources on the environment, although some of this may be due to students who are unfamiliar with the term “resources” and trouble interpreting “impact on the environment,” especially elementary school students. They also had to apply their knowledge of supply and waste disposal chains to think about the causes and ways to reduce global warming and why it might be important to preserve forests.

Implications for science curriculum and teaching

From our research, we set forth two goals for science curriculum and teaching. First, students must be aware of how the goods and services they depend on come from and return to natural environmental systems. Second, we advocate curriculum and teaching that helps students recognize the nature of the environmental impacts of the good and services they use. In order to address these goals, students must understand the *actors and locations/places, infrastructure and by-products,* and *transformation of matter and energy* that occurs as various products and services travel through supply and waste disposal chains.

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). Along with the *actors and locations/places* that interact at each end of supply and waste disposal chains, they need to recognize those involved throughout the 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 (practice 4). For example, 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. Student who mentioned the sun or weather and/or the earth's rotation as causes of global warming not only hold misconceptions, but fail to recognize the role that humans play in 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.

Limitations and future directions

This exploratory study provided us with insight into students' understanding of supply and waste disposal chains and environmental issues. In particular, we found that students have limited understanding of how products and services that we use are connected to environmental systems. There are limitations to this study due to the nature of the assessment. Students may understand more about the role humans play in supply and waste disposal chains and may not have mentioned it due to the wording and table structure of the questions (see Appendix A). For example, students probably know that humans are involved the production of beef; beef does not appear on ones' plate without the help of humans who raise cattle, butcher them, etc. Students may also know more about the infrastructure of systems than we saw evidence of in their paper and pencil assessments. They probably realize that there needs to be some type of infrastructure that brings resources and services to us, although they may still have an unclear idea of all of the infrastructure involved in supply and waste disposal chains. These results may be due to limitations of the paper and pencil assessments. It may also be due to the environment in which the assessments were given; students do not typically talk about supply and waste disposal chains in their science classes or make connections between human engineered and natural systems. Through other methods such as interviews, we may elicit more information and a deeper understanding of student knowledge of supply and waste disposal chains. We could specifically ask students about their understanding of infrastructure and transformation of matter. We could ask students about the by-products that various processes create and the impact these by-products have on the natural environment. The dishwashing question was the only question that asked students about the impact that using various resources has on the natural environment. We need more questions about the impact of using products and services on the environment. Students need to recognize both how humans are connected to and depend on environmental systems, but more importantly, they need to understand the impact that we have on environmental systems.

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

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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