Energy Flow through an Ecosystem: Conceptions of In-service Elementary and Middle School Teachers

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Abstract

This descriptive study investigated 53 in-service elementary and middle school teachers' understanding of basic concepts regarding energy flow through an ecosystem they likely are expected to teach. A multiple-choice instrument assessing selected standards-based life science concepts (i.e., essential needs of plants, photosynthesis and respiration, natural selection, energy flow through an ecosystem) with non-scientific conceptions embedded as distracter options was used in the study. Findings from five tasks regarding energy flow through an ecosystem suggest that the teachers sampled had conceptual difficulty with key standards-based energy flow concepts, particularly concerning the original energy source for a forest ecosystem, decomposers as nutrient recyclers rather than energy recyclers, and differentiating between primary and secondary consumers. Findings support the need for professional development regarding energy flow through an ecosystem for these teachers to address their non-scientific conceptions. Additionally, recommendations are provided for strengthening pre-service teacher education.

Key words: elementary school, middle school, energy flow, interactions in ecosystem

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Introduction

Improving student achievement in science has been a goal for science reform efforts over the past two decades. Unfortunately, results from the 2005 and 2009 National Assessment of Education Progress (NAEP) (Grigg, Lauko, & Brockway, 2006; National Centre for Education Statistics, NCES, 2011) show that fewer than 33% of 4th and 8th grade students, and only 21% of twelfth grade students in the United States, scored at or above “proficiency” in science. Proficiency is the level at which students demonstrate a solid foundation of reasoning skills and content knowledge necessary to be successful in science at a particular grade level.

Considering the plethora of studies on K-12 students’ non-scientific conceptions in physical science (see misconception database), it is not surprising that results from all three NAEP grade level assessments identified physical science as an area of weakness for students. Proficiency in life science concepts, specifically relating to energy flow through an ecosystem (Grigg et al., 2006) also has been an area of weakness on the NAEP assessment. More specifically, 59% of 8th grade students and 49% of 12th grade students surveyed were unable to identify the primary consumers in a food web, and 61% of 8th grade students were unable to identify the role of green algae in a pond ecosystem (Grigg et al., 2006). These results are particularly disturbing, considering the National Science Education Standards (NSES) (National Research Council [NRC], 1996) introduce these concepts in the upper elementary grades (grades 5-8).

The transformation of light energy into chemical energy through the process of photosynthesis begins the chain of energy transfer from plant to consumer and consumer to consumer (i.e., primary consumer, secondary consumer, decomposer) throughout a forest ecosystem. The transfer of energy from plant (producer) to consumer is a fundamental process that supports plant productivity and animal life throughout all the ecosystems around the world, and is an essential concept in understanding the interactions between organisms within ecosystems. Students’ understanding of this energy transfer chain, from this point forward referred to as energy flow through an ecosystem, is fundamental to understanding many life science concepts and is underscored as an essential life science concept in current science education standards documents (American Association for the Advancement of Science [AAAS], 1993; NRC, 1996; NRC, 2012), and is central to many current explorations for potential alternative energy sources in our world.

The growing body of research investigating students’ understanding of concepts regarding energy flow through an ecosystem has revealed specific non-scientific conceptions students frequently hold beginning at the elementary level and continuing through the college level (Adeniyi, 1985; Leach, Driver, Scott, & Wood-Robinson, 1996; Webb & Boltt, 1990; Gotwals & Songer, 2009). More disturbing, this research reveals that pre-service teachers demonstrate similar non-scientific conceptions (Atwood & Atwood, 1996; McDermott, 1991; Osborne & Freyberg, 1985; Trundle, Atwood, & Christopher, 2002; Yip, 1998). The continuation of low student achievement in science as revealed in the most recent NAEP results (NCES, 2011) and the difficulty college students have shown with concepts relating to energy flow through an ecosystem suggests the strong possibility that in-service elementary and middle school teachers might also experience difficulty with these standards-based concepts they are expected to teach.

Professional development programs can be an effective approach for helping in-service teachers improve their science content knowledge (Supovitz & Turner, 2000). However, in order to develop effective programs, it is important to identify specific standards-based concepts that are troublesome for teachers (Louks-Horsley, Stiles, & Howson, 1996). Thus, the purpose of this study was to investigate several groups of Central Appalachian in-service elementary and middle school teachers' understanding of basic concepts regarding energy flow through an ecosystem. The results from this study can help inform life science professional development programs for elementary and middle school teachers in the region and beyond.

Literature Review

Energy Flow through an Ecosystem: Science Content Standards and Conceptual Understanding

Important concepts regarding energy flow through an ecosystem are outlined in the K-8 NSES (NRC, 1996) for life science. According to these standards, elementary students (grades K-4) should develop an understanding of the interrelationships between biotic and abiotic factors in an environment. In addition, elementary students should be able to explain the feeding relationships between groups of organisms, such as producers and consumers, and develop the ability to predict accurately how a change in one population could affect other populations within the ecosystem.

In the middle school grades (grades 5-8) the NSES (NRC, 1996) asserts that students should be able to identify sunlight as the major source of energy for most ecosystems on Earth, and develop a general understanding of how plants convert light energy from the sun into chemical energy during photosynthesis. Subsequently, middle school students should develop an understanding of how this chemical energy is transferred from one organism to another in food chains and food webs. Students at this level also should understand relationships among various populations within an ecosystem, biotic and abiotic factors that limit populations in an ecosystem, and how the carrying capacity of an ecosystem affects the size and dynamics of populations therein.

Research has shown, however, that elementary students (ages 5-11) struggle with important concepts regarding energy flow through an ecosystem described in the NSES (NRC, 1996) (Abell & Roth, 1995; Lin & Hu, 2003; Leach et al., 1996; Özkan, Tekkaya, & Geban, 2004). For example, Leach et al. found that students (ages 5-16), whom they assessed through individual interviews and written tasks, appeared to understand some basic energy flow concepts, such as a predator-prey relationship between two specific organisms, but they had difficulty transferring this concept to the more global view of predator-prey relationships between two populations within an ecosystem. In addition, Abell and Roth found that many of the fifth grade students they studied thought food pyramids represented the space needs of organisms rather than the trophic levels and energy relationships among populations.

Additional studies have revealed that middle school students also have trouble with concepts related to energy flow through an ecosystem. For example, Adeniyi (1985) reported that the Nigerian students (ages 13-15) she interviewed could not define an ecosystem or habitat and often used the terms ecosystem and population interchangeably. Several other studies have found that students at this level tend to have difficulty explaining relationships among populations portrayed in food web diagrams and tracing the effects of changes in populations along several paths within the food web (Lin & Hu, 2003; Leach et al., 1996; Özkan et al., 2004). For example, Galegos, Jerezano, and Flores (1994) found that children (ages 10-12) have difficulty using food webs to trace energy flow through the trophic levels and tend to focus on interactions between populations in one food chain within a food web rather than focusing on other possible paths in the food web. In addition, Leach et al. found that 5-16 year-olds were better able to trace effects of a population change in a food web up through the trophic levels than in the reverse direction. Leach et al. also found that students at this level have difficulty differentiating between matter cycling and energy flow through an ecosystem.

Conceptual difficulties relating to energy flow through an ecosystem are not limited to students in the elementary and middle school grades. Research has shown that students in high school and college also demonstrate difficulties with these concepts (Anderson, Sheldon, & Dubay, 1990; Boyes & Stanisstreet, 1991; Webb & Boltt, 1990). For example, Ozay and Oztas (2003) found that high school students they sampled did not recognize plants as producers of chemical energy, which is transferred from organism to organism throughout the ecosystem. In addition, Webb and Boltt found that a majority of the high school and college students they studied could predict the probable effect on one organism in a food chain when a second organism was removed, but they could not successfully predict the effect on an entire food web if one population was eliminated.

Taken together, research studies discussed above regarding K-12 and college students' difficulty with concepts related to energy flow through an ecosystem suggest the likelihood that in-service elementary and middle school teachers might also experience similar conceptual difficulties. Although several studies suggest support for this premise (Mak, Yip, & Chung, 1999; Yip, 1998), research on US in-service elementary and middle school teachers' understanding is limited regarding energy flow through an ecosystem. For example, Mak et al. found that the in-service Chinese middle school teachers they surveyed held non-scientific conceptions about standards-based biological concepts; however, specific information regarding energy flow through an ecosystem was not provided. Similarly, Gess-Newsome and Lederman (1993) found that pre-service high school biology teachers with undergraduate degrees in biology or a related field held fragmented ideas about major biological concepts they were expected to teach.

Mismatch between Biology Instruction and Conceptual Understanding

It is troubling that traditional biology instruction at the K-12 and college levels does not appear to change students' preconceived non-scientific conceptions, even after instruction. More troubling are the findings from previous research studies that indicate no correlation between the number of biology courses completed at the undergraduate level and students' biological understanding (D'Avanzo, 2003; Nazario, Burrowes, & Rodriquez, 2002). Could these findings be a result of the type of instruction typically employed in the teaching of biology? In spite of existing research favouring constructivist, inquiry-based approaches to learning (Beeth, 1998; McDermott, Heron, Shaffer, & Stetzer, 2006; Vosniadou, 2007; Vosniadou, Ioannides, Dimitrakopoulou, & Papademetriou, 2001), most introductory-level biology courses, commonly required in elementary and middle school teacher preparation programs, implement a passive, lecture-based approach, which tends to emphasize breadth of content and the memorization of facts rather than an in-depth understanding of the concepts (Brewer & Berkowitz, 1998; D'Avanzo, 2003; Lord, 1997). This is poignantly illustrated in a survey of Ecological Society of America members who taught biology and ecology at the college level. Ninety percent of the members surveyed reported employing a passive lecture style approach in teaching introductory-level biology and ecology courses (Brewer & Berkowitz, 1998).

Teacher Subject Matter Knowledge and Student Learning

In order for teachers to help students effectively construct a scientific understanding of energy flow through an ecosystem, it is a logical premise that teachers must have a firm understanding of the concepts. Shulman (1987) noted that teachers' subject matter knowledge is an integral component of pedagogical content knowledge (PCK) and a necessary component of effective teaching. Current research in PCK (Hashweh, 2005) continues to underscore teachers' subject matter knowledge as a key component of teachers' pedagogical content knowledge for teaching science. Many studies have shown that teachers' subject matter knowledge plays a key role in determining what content is taught, how it is taught, and what pedagogical strategies chosen by teachers to teach the content to students (Grossman, Wilson, & Shulman, 1989; Grossman, 1995; Leinhardt & Smith, 1985; Thompson, 1984; Wilson, Shulman, & Richert, 1987). Findings from other studies also have shown that subject matter knowledge plays an important role in the level of questions teachers pose to students (Carlsen, 1991); in the construction of instructional activities they develop for students (Smith & Neale, 1989); and in their ability to develop new explanations in response to student questions (Smith & Neale, 1989). Begle (1972) and Hunkler (1968) also suggested that there is a direct relationship between teachers' depth of subject matter knowledge and students' depth of conceptual understanding.

Research also has shown that teachers' lack of subject matter knowledge negatively affects student learning and often results in limiting the content teachers teach. Specifically, some studies have found that teachers tend to teach content with which they are more familiar and avoid teaching content with which they are less familiar (Carlsen, 1991, Smith & Neale, 1989). Thus, it is not surprising that researchers have found that teachers with poor science backgrounds can negatively affect their students' understanding of science concepts (Gess-Newsome & Lederman, 1995; Johnson, 1998; Nott & Wellington, 1996).

Given the emphasis NSES (NRC, 1996) places on understanding energy flow through an ecosystem, it is critical that teachers have an in-depth scientific understanding of key concepts addressing this topic. Quality professional development programs that address concepts directly connected to standards teachers are expected to teach, address teachers' alternative conceptions, offer opportunities for teachers to actively develop their understanding, support the development of learning communities, and include follow-up meetings with teachers throughout the year have been effective in improving K-8 teachers' scientific understanding and pedagogy (Garet, Porter, Desimone, Birman, & Yoon, 2001; Supovitz & Turner, 2000). Identifying specific conceptual difficulties teachers experience is a prerequisite to the development of appropriate professional development instruction.

With this in mind, the purpose of this study was to identify conceptual difficulties a sample of South-eastern elementary and middle school in-service teachers experience with concepts relating to energy flow through an ecosystem. The question that guided this study was: What conceptions do South-eastern U.S. in-service elementary and middle school teachers have about basic ideas concerning energy flow through an ecosystem? Data collected from this study can help inform the development of professional development programs in life science for elementary and middle school teachers in the region.

Methods

Participants

Participants in this study included 53 self-selected in-service elementary and middle school teachers solicited from 51 rural school districts in the South-eastern region of the United States. The participants enrolled in one of four one-week life science institutes during the summer of 2006. Teachers ranged in experience from first-year novices to veterans with more than 20 years of experience. Two-thirds of the teachers taught elementary grades three through five, with a majority of these teachers teaching grades four and five. Middle level teachers taught in grades six through eight, with a majority teaching grade seven. School districts represented in the study were classified as rural by the National Centre for Education Statistics, and with over 50% of the student populations served receiving free or reduced lunch. All teachers, many of whom earned a generalist teaching certification for the elementary level, were certified to teach within their grade level, and a majority of the teachers were female.

The one-week summer institutes were part of a large math and science partnership project involving 51 school districts and 9 institutions of higher education within the region, with support from the National Science Foundation. One of the major goals of the project was to improve K-12 teachers' content knowledge in mathematics and science. To this end, the institutes in which study participants were enrolled focused on standards-based life science concepts addressed in grades 4-7. A panel of science teachers and science teacher educators from the region identified energy flow through an ecosystem, in addition to other life science topics, as particularly troublesome for students.

Grades 4-7 represent critical years for state science accountability assessments in school districts included in the study and are of great interest to teachers, science educators, and administrators beyond this region who are concerned about improving student achievement in science. Upper-elementary in-service teachers (grades 4-5) constituted a majority of participants. The limited number of middle school teachers participating in the study did not make it possible to differentiate between elementary and middle school teachers' responses without jeopardizing participants' anonymity. Therefore, teachers' responses are presented as one group and are not delineated further for the elementary and middle school groups, respectively.

Assessment Instrument

The five forced-choice tasks that serve as the data source for this study were part of a 20-item instrument employed to survey teachers' understanding of standards-based life science topics. The instrument was aligned with the NSES (NRC, 1996) in life science for grades K-8 and state science content standards represented in the South-eastern region. The instrument addressed four general concepts in life science: photosynthesis and respiration, energy flow in an ecosystem, heredity and natural selection, and experimental design. Only results for the tasks addressing energy flow through an ecosystem are discussed in this paper.

A group of science educators and biologists constructed the tasks for the four main topics listed above. The tasks were modelled after tasks included in the Conceptual Inventory of Natural Selection (CINS) (Anderson, Fisher, & Norman, 2002) and the Diagnostic Teacher Assessment in Mathematics and Science (DTAMS) (Tretter, Moore, Brown, Saderholm, Kemp, & Bush, 2005), and were aligned with the National Science Education Standards (NRC, 1996). Commonly held non-scientific conceptions as identified in the research literature (Simpson & Arnold, 1982; Eisen & Stavy, 1988; Munson, 1991; Munson 1994; Ozay & Oztas, 2003) were embedded in distractor options. Another panel of science educators and biologists reviewed the tasks for content and face validity. A pilot test was administered to a group of elementary and middle level in-service teachers that participated in similar life science teacher institute the previous year. Analysis of the pilot test results resulted in a reliable level of internal consistency with a coefficient alpha of .77. The forced-choice format was selected in order to conform to the time limitation that existed during the institutes. The assessment instrument was completed anonymously in order to relieve teachers' anxiety about potential negative effects of poor test results.

Data Analysis

Frequencies and percentages were calculated for responses to each of the five assessment tasks. Correct responses reflected a scientific understanding, whereas incorrect responses helped identify non-scientific understandings. Incorrect response frequencies also indicated the extent to which teachers sampled held particular non-scientific conceptions. Item response frequencies were further divided into three performance subgroups depending upon how respondents performed on the entire instrument. Respondents scoring in the top third on the entire instrument were placed in the high performance subgroup, respondents scoring in the midrange on the entire instrument were placed in the middle performance subgroup, and respondents scoring in the lower third on the entire instrument were placed in the low performance subgroup. Subgroup frequencies that otherwise would have been masked by only examining results for the entire sample were used to identify the prevalence of non-scientific conceptions within each subgroup and across the subgroups.

Results

Results from the five forced-choice tasks regarding energy flow through an ecosystem are discussed in this section. More specifically, these tasks focused on sunlight as the primary energy source in an ecosystem, the role of decomposers in an ecosystem, trophic levels within a food chain and the energy relationships among trophic levels, and feeding relationships among organisms in a food web. In this section a summary table is provided for each task showing the frequency distributions for each option (A-E), with the correct answer identified in bold-faced type. As indicated, responses for each task were further divided into three subgroups, based on how teachers performed on the entire assessment instrument. The first three rows in each summary table represent responses from the high, middle, and low performance subgroups, respectively. The fourth row shows the total frequencies for each option, and the fifth row shows the frequencies expressed as percentages.

Task 1 assesses the understanding of the sun as the primary source of energy (option D) for a forest ecosystem. While a few ecosystems on Earth, such as around deep sea vents, do not require sunlight as an energy source, the sun is the original source of energy for most ecosystems on Earth. A forest was selected for this task because it was thought that the teachers in the region likely would be familiar with this ecosystem. The results from this task are encouraging. As Table 1 indicates, 48 of 53 teachers (90.6%) in the sample identified the sun as the original energy source for a forest ecosystem. Option A, green plants, was the most popular distractor for the middle and low performance subgroups. Teachers selecting option A might have misinterpreted the stem for this question and identified the original source of food for the ecosystem rather than energy, since food is part of the stem in this task. Alternatively, teachers selecting option A also might have had a partial understanding of the primary energy source for this ecosystem, since plants transform the sunlight into chemical energy, which is a usable form of energy for the ecosystem.

School textbooks and curricula regarding energy flow through ecosystems have been criticized for containing oversimplified or misleading ideas, as well as mistakes, that may contribute to the development of students' non-scientific conceptions (Barrass, 1984; Grotzner & Basca, 2003). This might be true, especially in the case of the sun as the primary energy source in an ecosystem. A review of food web diagrams portrayed in popular K-12 science textbooks in the Central Appalachian region revealed that figures portraying food webs typically do not include the sun and, thus, promotes the non-scientific conception that plants are the primary energy source for terrestrial ecosystems.

Table 1. *Response Frequencies by Performance Subgroup for Task 1, Original Source of Energy in a Forest Ecosystem*

Task 1. What is the **original** energy source for all of the food webs in a forest?

A. green plants
B. consumers
C. decomposers
D. sunlight
E. soil nutrients

	Answer Options						
Subgroups	A	B	C	**D**	E	omit	Total
High	0	0	0	**17**	0	0	17
Medium	1	0	0	**18**	0	0	19
Low	3	0	1	**13**	0	0	17
Totals as *f*	4	0	1	**48**	0	0	53
Totals as %	7.5	0	1.9	**90.6**	0	0	100

Boyes and Stanisstreet (1991) also found that first-year undergraduate students understood that plants get their energy from the sun, but they also thought that soil, air, water, and animals were additional sources of energy within the ecosystem. Likewise, Krall, Lott, and Wymer (2009) found that, in addition to the sun, elementary and middle level teachers from the Central Appalachian region also identified soil and water as additional energy sources for an ecosystem. The forced-choice format used in the current study limits the ability to determine if the teachers who selected option A also thought there were other sources of energy in a forest ecosystem in addition to sunlight. Additional research is needed to investigate this possibility.

Task 2 (Table 2) focused on the role that decomposers play in an ecosystem. Specifically, the task assessed whether the teachers sampled understood decomposers to be the recyclers of nutrients, but not energy, in an ecosystem. Responses indicated that teachers had much more difficulty with Task 2 than Task 1. Specifically, only 28 of 53 teachers (52.8%) demonstrated the correct understanding that decomposers, such as fungi and bacteria, are the nutrient recyclers in an ecosystem. These heterotrophs break down organic material into inorganic compounds that plants then absorb as nutrients to support life processes. However, only 5 of 17 teachers (29.4%) in the high performance subgroup, 9 of 19 teachers in the middle performance subgroup (47.4%), and 9 of 17 teachers (52.9%) in the low performance subgroup demonstrated the understanding that decomposers recycled energy (option C), rather than nutrients. These responses suggest that many teachers in the sample have developed only a partial understanding of the role decomposers play in an ecosystem and that too many teachers in all three subgroups had difficulty differentiating between nutrient recycling and a unidirectional flow of energy in an ecosystem.

Table 2. *Response Frequencies by Performance Subgroup for Task 2, Decomposers as Nutrient Recyclers in Ecosystems*

Task 2. Organisms classified biologically as decomposers

A. make their own food through photosynthesis for consumers.
B. break down organic matter into its simpler components for use by green plants.
C. recycle energy from dead matter back into the ecosystem for use by green plants.
D. provide oxygen to consumers.
E. provide carbon dioxide to consumers.

	Answer Options						
Subgroups	A	B	C	D	E	omit	Total
High	0	12	5	0	0	0	17
Medium	0	10	9	0	0	0	19
Low	1	6	9	1	0	0	17
Totals as *f*	1	28	23	1	0	0	53
Totals as %	1.9	52.8	43.4	1.9	0	0	100

Teachers in the current study appear to recognize that decomposers break down dead material into its simpler chemical components. It is possible that the teachers selecting option C confused the term energy with nutrients, as is often the case with middle school students (Leach et al., 1996). Regardless, the selection of option C suggests these teachers lack a deep understanding of nutrient cycling versus energy flow in an ecosystem.

These findings also suggest that teachers in the current study have developed a better understanding of the role of decomposers in an ecosystem than a group of seventh graders examined in a previous study. Specifically, the fourth grade students that Demetriou, Korfiatis, & Constantinou (2009) assessed demonstrated difficulty identifying trophic relationships involving decomposers. Furthermore, Smith and Anderson (1986) found that the seventh grade students they assessed considered dead organisms as simply rotting away and failed to recognize that decomposers break down nutrients, in the form of inorganic compounds, from dead organisms and return these compounds back to the soil for use by plants.

Task 3 (Table 3) narrowed the concept of energy flow within an ecosystem to the simplified elementary level concept of energy flow through food chains. In this task, participants were expected to recognize plants as the producers of chemical energy for this food chain. They also were expected to understand that some of the chemical energy in each trophic level is transformed into other energy forms, such as thermal energy, that are inaccessible to organisms in an ecosystem. Thus, not all of the energy in one trophic level is transferred to the next trophic level.

A review of the results for this task reveals that 32 of 53 teachers in the sample (60.4%) selected the correct response, option C. However, the bimodal distribution for the two most popular distractor options, A and D, suggests that 18.9% of the teachers sampled demonstrated common non-scientific conceptions about energy flow in an ecosystem. Specifically, 4 of 19 (21.1%) and 6 of 17 (35.3%) teachers in the middle and low performance subgroups, respectively, selected the distractor supporting the non-scientific notion that the soil is an energy source for organisms in an ecosystem. In addition, 4 of 19 (20.4%) and 2 of 17 (11.8%) of the teachers in the middle and low subgroups, respectively, selected the distractor consistent with the non-scientific conception that all of the energy from one trophic level is passed to the next higher level. Although, the answer options include both long and shorter options, options C, D, and E were purposefully made longer to detract participants from selecting a longer answer choice. Participants' selection of all five choices suggests the varying answer option lengths was not an issue in answer option selection.

Table 3. *Response Frequencies by Performance Subgroup for Task 3, Energy in a Food Chain*

Task 3. Consider the following food chain: Grass➔ cricket ➔ frog ➔ snake

Which of the following is true?

A. Energy for the food chain comes from the soil.

B. There probably are more snakes than frogs in this community.

C. There is more energy available to frogs in the form of crickets than is available to snakes in the form of frogs.

D. All of the energy in crickets that are eaten by frogs is transformed into energy in the form of the frog's flesh.

E. Unlike the animal organisms in the food chain, grass does not depend upon an energy source to survive.

Subgroups	Answer Options					Omit	Total
	A	B	C	D	E		
High	1	0	**15**	1	0	0	17
Medium	4	0	**11**	4	0	0	19
Low	6	1	**6**	2	2	0	17
Totals as *f*	11	1	**32**	7	2	0	53
Totals as %	20.8	1.9	**60.4**	13.2	3.8	0	100.1

Note: Total percentage does not equal 100 due to rounding answer option data

In contrast, Adeniyi (1985) found that only a small percentage (7.7%) of students ages 13- 15 years demonstrated this non-scientific notion. Although only a few teachers in the current study selected this non-scientific option, their responses indicate the likelihood that they are teaching the non-scientific conception that the soil and other organisms are, in addition to the sun, producers of energy for the ecosystem.

Task 4 (Table 4) assesses teachers' understanding of the terminology used to describe trophic levels in a food chain. Only 31 of 53 teachers (58.5%) in this study correctly identified the mackerel as both a carnivore and a secondary consumer (option B). The bimodal distribution shown for options C and D suggests that the teachers in the middle and low performance subgroups had difficulty with the role of larvae in this food chain. In particular, 5 of 19 teachers (26.3%) in the middle performance subgroup and 7 of 17 teachers (41.2%) in the low performance subgroup identified the mackerel as a primary consumer (options C and D). The selection of these two options implies that these teachers might have considered the larvae as producers in this food chain. This was the case in Adeniyi's (1985) study of Nigerian students (ages 13-14). Specifically, Adeniyi found that students at this level identified plants, butterflies, and other small organisms as producers because they served as a food source for other organisms in an ecosystem.

Table 4. *Response Frequencies by Performance Subgroup for Task 4, Trophic Levels in a Food Chain*

Task 4. In the food chain shown below, the mackerel is a(n) _______ and a(n) ________.

algae → larvae → mackerel → shark,

A. autotroph, consumer

B. carnivore, secondary consumer

C. herbivore, primary consumer

D. carnivore, primary consumer

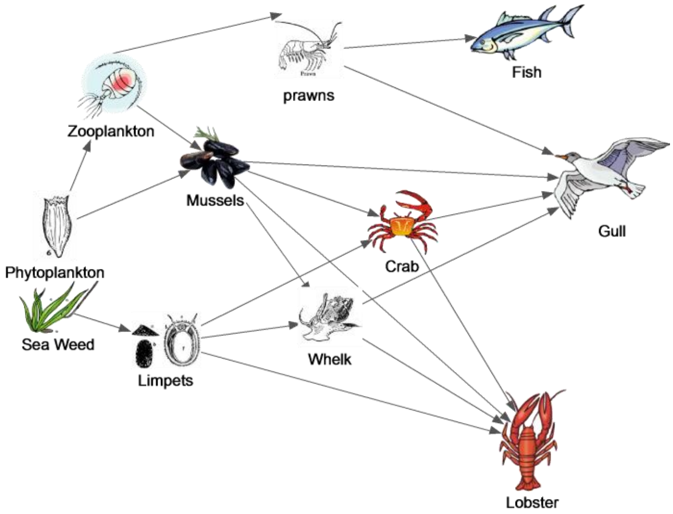
E. herbivore, secondary consumer

	Answer Options						
Subgroups	A	**B**	C	D	E	omit	Total
High	0	**14**	0	2	1	0	17
Medium	1	**11**	3	2	2	0	19
Low	2	**6**	4	3	2	0	17
Totals as *f*	3	**31**	7	7	5	0	53
Totals as %	5.7	**58.5**	13.2	13.2	9.4	0	100

Results from the current study suggest some of the teachers in the middle and low performing subgroups might share this non-scientific notion. Respondents' selection of option D, which suggests carnivores can be primary consumers, further supports this inference.

Task 5 (Table 5) expands the simplified concept of a food chain to the more complex concept of a food web, specifically considering the effect a sharp increase in one population would have on other populations within the ecosystem. The teachers in the sample performed fairly well on this task, with 38 of 53 teachers (71.7%) correctly selecting option A. The selection of this option demonstrated the scientific understanding that an increase in a particular primary consumer population would result in an increase in the populations of secondary consumers that prey on them. Note that all the respondents in the high performance subgroup correctly selected option A. In comparison, only 12 of 19 teachers (63.2%) and 9 of 17 (52.9%) teachers in the middle and low performance subgroups, respectively, selected this option.

Table 5. *Response Frequencies by Performance Subgroup for Task 5, Relationships between Organisms in a Food Web*



Task 5. In the food web shown above, if the number of mussels increased sharply over a few years, the most likely result would be

A. an increase in the number of crabs.

B. an increase in the number of fish.

C. an increase in the number of phytoplankton.

D. a decrease in the number of gulls.

E. a decrease in the number of lobsters.

	Answer Options						
Subgroups	**A**	B	C	D	E	Omit	Total
High	**17**	0	0	0	0	0	17
Medium	**12**	1	4	2	0	0	19
Low	**9**	1	4	1	2	0	17
Totals as *f*	**38**	2	8	3	2	0	53
Totals as %	**71.7**	3.8	15.1	5.7	3.8	0	100.1

Note: Total percentage does not equal 100 due to rounding answer option data

It is disturbing to note that option C was the most common distractor. This option was selected by 4 of 19 teachers (21.1%) in the medium performance subgroup and 4 of 17 teachers (23.5%) in the low performance subgroup. Teachers selecting option C simply might have overanalysed the question, reasoning that a rise in the phytoplankton population would initiate a rise in the mussel population.

Findings from Task 5 for this group of teachers are similar to the results from studies of middle school students' understandings of energy flow through an ecosystem. In particular, Leach et al. (1996) and Barman, Griffiths, and Okebukola (1995) noted that many middle school students misinterpreted the direction of arrows in food web diagrams and experienced more difficulty tracing effects down through trophic levels (e.g., from tertiary consumer to producer) than up through trophic levels. Furthermore, Barman et al. found that students often developed the simplistic non-scientific notion that a change in one population will only affect organisms along one path of the food web that are directly linked to that species, such as in a single predator-prey relationship. Similarly, the 11 year old students that Hogan (2000) assessed tended to focus on local rather than extended effects within a food web.

Given the results from these previous studies, one might think that in-service teachers would identify energy flow through an ecosystem as a difficult concept for students to understand. However, in a survey administered to 100 teachers who taught earth, life, and physical science, most teachers considered food webs relatively easy for students to grasp (Finlay, Stewart, & Yarroch, 1982). That finding is not consistent with the findings from Task 5 in the current study or from previous studies discussed earlier (Barman et al., 1995; Leach et al., 1996; Hogan, 2000).

In summary, of the 265 possible correct responses on the five tasks discussed, 177 (66.8%) correct responses were selected. A comparison of the high, middle, and low performance subgroups reveals disparities in content understanding, particularly across the middle and low performance groups. Specifically, the middle performance subgroup selected 62 of a possible 95 correct responses (65.3%), whereas the low performance subgroup selected only 40 of a possible 85 (47%) correct responses. This disparity indicates the performance of the high subgroup positively skews the performance of the entire sample and masks the much weaker understanding of the teachers in the middle and low subgroups.

Specific areas of concern for teachers in the current study included differentiating between nutrient recycling and unidirectional energy flow in an ecosystem, and understanding the role of decomposers in an ecosystem. Teachers also showed limited understanding of relationships among organisms in food chains and food webs and energy flow from one trophic level to another. Identifying the soil, rather than the sun, as an energy source for a forest ecosystem was another troublesome concept for teachers in the sample. These concepts are fundamental to energy flow in an ecosystem and important building blocks for further studies in life science.

Conclusion and Implications

The results from this study indicate that most of the teachers sampled did not have an adequate understanding of key standards-based science concepts concerning energy flow through an ecosystem that they reasonably may be expected to teach. Furthermore, teachers' responses frequently reflected the same non-scientific conceptions about energy flow through an ecosystem that elementary and middle school students have demonstrated in previous research studies (Adeniyi, 1985; Leach et al., 1996; Smith & Anderson, 1986; Hogan, 2000; Gotwals & Songer, 2009). Findings from the current study are of great concern considering the responsibility K-8 teachers have in helping their students develop a strong scientific understanding of these concepts.

In addition, results from the 2005 and 2009 NAEP (Grigg et al., 2006; NCES 2011 2011) indicate that student achievement in science at the elementary and middle school levels has remained disappointingly low and has shown little change at the proficient and advanced levels over the past decade. Poor student proficiency demonstrated on the 2005 NAEP regarding energy flow through an ecosystem suggests the likelihood that elementary and middle school teachers outside the central Appalachian region also struggle with these concepts. Additional research is needed to identify the pervasiveness of these non-scientific conceptions among in-service elementary and middle school teachers within the region and beyond.

This study also adds to the growing body of research on pre-service and in-service elementary and middle school teachers' understandings of life science concepts. Based on the findings from the current study and other studies discussed earlier in the paper (Gess-Newsome & Lederman, 1993; Mak et al., 1994; Yip, 1998), further research is needed to characterize elementary and middle school teachers' understandings of energy flow through an ecosystem. Specifically, additional research is needed to clarify teachers' understanding of: (1) sources of energy for a food web; (2) identification of consumers, producers and the interrelationships between these organisms in an ecosystem; (3) energy flow through an ecosystem at the organism and population levels; and (4) nutrient cycling in an ecosystem. Future studies also should use individual interviews to help provide more complete descriptions of teachers' conceptual frameworks for these important topics. Data collected from such studies could help inform needed improvements in pre-service and in-service teacher preparation programs in the region and beyond.

The development of teachers' science content knowledge is a complex issue. Elementary and middle school teacher preparation programs are designed to help teachers' construct a strong foundation of concepts they are expected to teach. However, as Grossman et al. (1989) and Grossman (1995) assert, teachers need to continue to develop their content understanding long after their completion of a teacher preparation program. Quality professional development can help teachers further improve their understanding of important concepts relating to energy flow through an ecosystem. The findings from the current study informed the selection of activities used in the summer life science teacher institutes and guided the development of an inquiry-based biology course for pre-service teachers that was piloted during the 2007-2008 school year. Data were being analysed to evaluate the success of these programs at the writing of this paper and hopefully can be used to enhance future teacher preparation programs and quality professional development for teachers at these levels.

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