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Evaluation of Students' Energy Conception in Environmental Science

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ABSTRACT

While significant research has been conducted on students' conceptions of energy, alternative conceptions of energy have not been actively explored in the area of environmental science. The purpose of this study is to examine students' alternative conceptions in the environmental science discipline through the analysis of responses of first year college students in the U.S. (N = 86) to an environmental science energy test. Each item in the test consists of a multiple choice question followed by an open-ended question asking students to justify their choice for the multiple choice question. Students' written responses were analyzed using an open-coding method. Results showed several alternative conceptions regarding each of the various energy aspects within the environmental science discipline. The findings of this study can potentially guide the development environmental science curriculum, particularly in regard to teaching the energy concept.

KEYWORDS
Alternative conceptions, energy, environmental science, test

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Introduction

Energy is a key and useful concept for explaining various scientific phenomena across science disciplines. In the US, *The Next Generation Science Standards* (NGSS Lead States, 2013) and National Research Council (NRC) report, *A Framework for K-12 Science Education: Practices, Crosscutting Concepts, and Core Ideas* (NRC 2012), include energy as a cross-cutting and core disciplinary concept. In recent years, the environmental science discipline has been actively adopting interdisciplinary contexts for its education and research areas (Focht and Abramson 2009; Hackett and Rhoten 2009; Semerjian, El-Fadel,

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Zurayk, and Nuwayhid 2004; Tapio and Willamo 2008). Internationally, calls for the environmental education have emphasized the interplay between scientific disciplines (Vogt, Fischer, and Hauer 2015), suggesting that environmental sciences programs should be interdisciplinary and include various aspects of science disciplines including engineering (Tansel 1994; Wiesner and Theis, 1996). This demand for interdisciplinary environmental education is expanding across the US (Vincent and Focht 2011). As such, students' conceptions of energy in environmental science, which has innate interdisciplinary contexts, are worthy of investigation. Investigation of students' alternative conceptions in environmental science can provide teachers with resources to inform content and pedagogical decisions for teaching the energy concept.

Although energy is one of the most central and richly connected ideas across the science disciplines, students often have a great deal of difficulty in understanding it (Driver, Squires, Rushworth, and Wood-Robinson 2004). Many studies have found that students hold alternative conceptions about energy, due in part to the fact that it already exists in their everyday lexicon and experience, thus they come to school with a variety of preexisting conceptions before instruction (Lijnse 1990; Trumper 1990). Solomon (1983) posited that, "meanings which are in daily use cannot be obliterated by science lessons" (p. 129). Despite instruction, these meanings remain, often in conflict with accepted scientific understandings and influencing students' understandings in science class.

Moreover, the energy concept is defined and used in different ways depending on the contexts (Cooper and Klymkowsky 2013; Lancor 2014). Lancor (2014) found that students' understanding of the energy concept is often incompatible between different scientific contexts, even within a same discipline. Here, context refers to scientific disciplines (e.g., physics, chemistry, or environmental science etc.) or particular science topics such as mechanics, circuits, or ecosystem (e.g., Lancor 2014). Also, many studies support a hierarchical sequence of energy aspects in assessment item difficulty (e.g., Dawson 2006; Lee and Liu 2010; Liu and McKeough 2005; Neumann, Viering, Boone, and Fischer 2013). Specifically, four energy aspects, i.e., (1) energy has various sources and forms (Source/Form), (2) energy is transferred from one form to another (Transfer), (3) while energy is transferred, the value of it decreases (Degradation), and (4) the total amount of energy does not change during transfer or degradation (Conservation) (Liu and McKeough 2005; Duit, 1984), are hierarchically ordered in item difficulty, which indicates that understanding of energy conservation is the most difficult for students, followed by understanding of energy degradation, transfer, and source/form.

While significant research has been conducted on students' conceptions of energy in the K-12 levels, there is a surprising lack of studies on students' conceptions of energy in environmental science given the prominence of environmental initiatives in the mainstream media and public interests. The number of prior studies on energy conception targeted at college level students is also limited, thus our study focused on college students' energy conceptions in environmental science to addresses this gap.

The purpose of this study is to investigate their alternative conceptions about energy in the environmental science discipline. In this study, students were prompted to answer an item set, including a multiple choice (MC) question and an open-ended (OE) question, investigating their conceptions of energy in the environmental science discipline. Students' alternative conceptions of energy were identified through analysis of their responses to the OE questions.

Literature Review

Students' Conceptions about Energy

Integrating Research in science education has shown that students across all grade levels have substantial difficulties in understanding energy concepts (Chabalengula, Sanders, and Mumba 2012; Liu, Ebenezer, and Fraser 2002). Students enter school with a variety of pre-conceptions of energy stemming from their everyday experience and language (Duit 1981, 1984; Lijnse 1990; Solomon 1983; Trumper 1990). This can often lead to confusion between scientific terms relating to energy, resulting in difficulty in learning the energy concept.

A variety of studies have investigated the conceptions of energy that students bring with them to science class. Solomon (1983) identified four themes in students' conceptions of energy: vitalism (energy is needed to live), activity (energy is needed to move), fuel (energy is needed to run machines), and world energy shortage (need for new sources of energy). These themes are reflective of the ways that energy is used outside of the science classroom and represent meanings that both co-exist and conflict with those taught through directed instruction in science class, and can influence students' understanding of related science topics. Watts (1983) described frameworks illustrating students' views of the energy concept consisting of seven kinds of alternative conceptions of energy; human centered energy, a depository model of energy, energy as an ingredient, energy as an obvious activity, energy as a product, energy as functional, and a flow-transfer model of energy.

Numerous empirical studies found students' confusion between energy and other scientific concepts. For example, students have considerable difficulties in differentiating between force and energy or power and energy (Trumper 1998; Watts and Gilbert 1983), energy and voltage (Goldring and Osborne 1994), and temperature and heat (Clough and Driver 1985; Harrison, Grayson, and Treagust 1999; Lewis and Linn 1994). In addition, many students consider that only moving objects possess energy, and energy is needed to be doing something (Trumper 1998). Chabalengula, Sanders, and Mumba (2012) found that many students believed that there is no energy involved or present in inanimate objects. Similarly, Barak, Gorodetsky and Chipman (1997) reported the problem that energy is considered to be a vitalistic notion. Despite energy being a central concept across science disciplines, research has consistently shown that students bring with them a variety of alternative conceptions. These conceptions are apparent across science disciplines and often persist even after instruction.

Alternate Conceptions in Environmental Science

McComas (2002) and Munson (1994) presented a variety of alternative conceptions based on general perceptions of environmental opinions and research studies on ecological conceptions that were available. These included alternative conceptions with regards to food chains and webs, ecological adaptations, population size and carrying capacity, and ecosystems and populations.

Regarding students' conceptions on food chains and webs, many studies found that students do not understand the complexity and interconnection characteristics of food chains and food webs. Barman, Griffiths, and Okebukola

(1995) found that the majority of students had difficulty in describing the concepts of food chains and webs, and only a few students described feeding relationships as a means of energy transfer among organisms. Even successful students continued to misunderstand the relationship between food (matter) and energy, indicating that food is converted to energy rather than releasing energy as it is converted into non-food materials (Smith and Anderson 1986). Students often do not understand the complex nature of how matter and energy flow in an ecosystem (Hogan 2000; Smith and Anderson 1986), believing instead that energy flows through the food pyramid from bottom to the top. As with the misunderstanding of how matter and energy transfer through the food web, students may not realize that chemical pollutants change in form as they move through food chains, overstating the importance of initial contact with pollutants without acknowledging the cumulative effect of pollution moving through the chain (McComas 2002). In addition to alternative conceptions about energy flow, Boyes and Stanisstreet (1991) said that, while students understood that plants get their energy from the sun, they also thought that soil, air, water, and animals were additional sources of energy within the ecosystem. Alternative conceptions about food chains and webs were not only found in students, but also in teachers. Beals, Krall and Wymer (2012) investigated elementary and middle school teachers' understanding of energy flow through an ecosystem and found that most of them did not have an adequate understanding regarding the energy source for a forest ecosystem and energy flow across trophic levels.

The complex interrelationships between organisms in ecosystems seem very difficult for students to understand. Research has shown that students tend to have difficulty in understanding the complex interrelationship between population size and environmental factors (Gallegos, Jerezano, and Flores 1994; Leach, Driver, Scott, and Wood-Robinson 1996; Lin and Hu 2003). Students may not realize that limited resources, like food supply, will limit populations or, if the limits are acknowledged, they may believe that if the limits are reached, the population will crash and the organisms will become extinct (Munson 1994).

Many studies have been conducted about ecological conceptions, but given the prominence of environmental initiatives in the mainstream media and public interest, there is a surprising lack of studies on students' conceptions of alternative energy. Tortop (2012) investigated high school students' awareness of renewable energy resources and applications (RERAs), and found that they have a very low level of awareness and knowledge of RERAs and hold several alternative conceptions. Çoker, Çatlıoğlu and Birgin (2010) also found that students had difficulty in identifying renewable energy sources. Alternative and renewable energy are common topics in both scientific discussion and popular media with respect to economical, environmental, and societal issues. Thus there is a need to investigate students' conceptions about alternative energy to better prepare an informed citizenry to participate in these discussions. Also, given that majority of studies on students' conceptions of energy in the environmental science were conducted with K-12 students, an investigation of college students' energy conceptions in the discipline is required to expand the scope of the body of literature.

Methodology

Measurement Instrument

In order to investigate students' conceptions of energy in the environmental science discipline, a published energy measurement instrument (Author, 2016) was used. The instrument was developed to assess students' energy conceptions in multiple disciplines, consisting of four test forms, physics, chemistry, biology, and environmental science. In this study, the environmental science test form was used to examine students' conceptions about energy. The environmental science test form contains two main science content topics within the environmental science discipline, energy in ecosystems including food chains (EE) and alternative energy/energy efficiency (EA), and consists of eleven items. MC questions alone do not provide enough information about students' reasoning (Peterson, Treagust and Garnet 1989), therefore each item consisted of an MC question and an OE justification question to investigate students' conceptions more thoroughly. These second tier OE questions elicit students' reasoning for their selections made in the first tier, MC questions. Chandrasegaran, Treagust and Mocerino (2007) mentioned that students' justifications provide an effective way to identify students' alternative conceptions. In addition, each item was designed to address one of the various energy aspects, including energy source, transfer, degradation, and conservation (Liu and McKeough 2005). The four energy aspects were suggested from the results of many studies for the teaching of students in a hierarchical order (e.g., Liu and McKeough, 2005; Lee and Liu, 2010; Neumann, Viering, Boone and Fischer, 2013).

Field-Test of the Environmental Science Test

The environmental test form was administered to college students in the U.S. (N= 86) who were taking at least one beginning level science course related to the environmental science discipline, i.e., atmosphere science and environmental biology, which involve the study of atmospheric processes and characteristics and the study of ecological relationships between living organisms and their ecosystems, in the spring semester of 2013. The students were recruited as whole classes, taught by two professors in the U.S. Students took the test during their class time, taking approximately 20 to 30 minutes complete when it was administered. Among participant students, n = 49 (57 %) students were female and n = 37 (43 %) students were male.

Data Analysis

Students' responses to OE questions were analyzed using the open-coding method by the authors and reported as frequency counts. All responses were analyzed and categorized, as codes were developed to explore themes in student responses as they emerged. After a line-by-line analysis of each written response, categories of response codes were developed. All discrepancies in coding between authors were discussed collectively until agreement was reached. After the recursive categorization process for the scientific correctness of the responses was completed, assertions were formulated regarding student conceptions of energy presented in their OE responses. Frequency counts were obtained to determine the actual number of students showing each alternative conception associated with their selected choice in each MC question. As students' alternative conceptions were analyzed using the open-coding method, we excluded instances when students' responses involved no response, restatement of the multiple choice option, stating that the response was a guess, or statements including "don't know" or "learned before".

Findings

Students' Conception about Energy

Analysis of student OE responses revealed several alternative conceptions regarding the various energy aspects in the environmental science discipline. Table 1 displays the results classifying students' alternative conceptions identified in this study.

Table 1. Classification of Students' Alternative Conceptions

Energy Aspect	Item # (topic)	Selection in MC Choices [a]	Alternative Conception Code	N[b]	Excluded N[c] (%)	Correct Response N (%)
Source	Q1 (EE)	A	Wind moves the water	11	22 (25.6)	30 (35.0)
		B	Earth rotation causes water cycle	1		
			Sun provides power to water	2		
		C	Earth rotation cause water cycle	2		
		D	Sun's gravity pulls water	18		
	Q6 (EA)	A	Alternative E is supplementary or alternative	5	15 (17.4)	33 (38.4)
			Alternative E is the one creating E from nothing	1		
		B	Nature one is alternative energy	18		
			Alternative E is supplementary or alternative	3		
		D	Alternative E is supplementary or alternative	9		
			Alternative E is the one reducing the cost	2		
Transfer	Q2 (EE)	A	Sun's heat is stored as calories along the food chain	4	16 (18.6)	46 (53.5)
		B	Energy is matter	4		
		C	Sun's heat is stored as calories along the food chain	3		
			Energy is used up	1		
		E	Sun's heat is stored as calories along the food chain	2		
			Kinetic E is passing along the food chain	7		
			E is matter	2		
			E is used up	1		
	Q7 (EA)	A	E is matter	13	35 (40.7)	27 (31.4)
			E is created	6		
		B	E is created	2		
			Heat is converted to electricity since hydro means heat in a hydroelectricity station	2		
		C	E is matter	1		
Degradation	Q3 (EE)	A	No E degradation along the food chain	29	20 (23.3)	10 (11.6)
		E	E is used up	19		
			E is matter	8		

Table 1. Classification of Students' Alternative Conceptions (Continued)

Energy Aspect	Item # (topic)	Selection in MC Choices [a]	Alternative Conception Code	N[b]	Excluded N[c] (%)	Correct Response N (%)
Degradation	Q4 (EE)	A	E is created	30	19 (22.1)	3 (3.5)
			No E degradation along the ecosystem	4		
			E is matter	1		
		B	No E degradation along the ecosystem	1		
			E is used up	11		
		C	No E degradation along the ecosystem	14		
			E is used up	2		
			E is matter	1		
	Q11 (EE)	A	E is matter	3	48 (55.8)	12 (14.0)
		B	E is matter	2		
		C	E is matter	4		
			Useful E has more E	1		
		D	E is used up	13		
			E is matter	2		
			Useful E has more E	1		
	Q8 (EA)	A	The amount of input E decides that of output E	20	27 (31.4)	12 (14.0)
			Alternative one can't be better	2		
		B	The amount of input E decides that of output E	19		
		C	Useful E has more E	3		
		D	Alternative one can't be better	3		
	Q9 (EA)	A	No E degradation	13	18 (20.9)	12 (14.0)
		B	E is used up	10		
			No E degradation	1		
			E is created by a turbine	13		
			E is matter	4		
		C	E is used up	7		
			No E degradation	1		
			E is created by a turbine	2		
			E is matter	5		
Conservation	Q5 (EE)	A	E is created	30	13 (15.1)	20 (23.3)
			No E degradation along the ecosystem	3		
			E is matter	3		
		B	E is used up	10		
			E is matter	1		
		C	No E degradation along the ecosystem	5		
			E is vitality	1		

Table 1. Classification of Students' Alternative Conceptions (Continued)

Energy Aspect	Item # (topic)	Selection in MC Choices [a]	Alternative Conception Code	N[b]	Excluded N[c] (%)	Correct Response N (%)
Conservation	Q10 (EA)	A	E is created	26	24 (27.9)	18 (21.0)
		B	E is used up to spin a rotor	5		
			E is matter	1		
		C	The amount of input E decides	2		
			that of output E	3		
			No E degradation	1		
			E is matter			
		D	The amount of input E decides that of output E	6		
Conservation	Q5 (EE)	A	E is created	30	13 (15.1)	20 (23.3)
			No E degradation along the	3		
			ecosystem	3		
			E is matter			
		B	E is used up	10		
			E is matter	1		
		C	No E degradation along the	5		
			ecosystem	1		
			E is vitality			
	Q10 (EA)	A	E is created	26	24 (27.9)	18 (21.0)
		B	E is used up to spin a rotor	5		
			E is matter	1		
		C	The amount of input E decides	2		
			that of output E	3		
			No E degradation	1		
			E is matter			
		D	The amount of input E decides that of output E	6		

Note. a. We excluded the MC choices if less than 1% of students chose the option.
b. N is number of responses was classified by code.
c. Excluded responses include: When students' responses involved no response, restatement of the multiple choice option, stating that the response was a guess, or statements like "don't know" or "learned before", those responses were excluded in the analysis.

Conceptions about Energy Source

In the EE content topic, when asked to identify the energy source/form for the water cycle (Q1), less than half of the students who provided their reasoning for their multiple choice response associated the Sun's radiation to its energy ($n = 30$, 35.0 %), while the majority of students provided various other energy sources. The most frequent alternative conception regarding identifying other sources was "the Sun's gravity pulls the water" ($n = 18$). This conception was commonly found students who chose the Sun's gravity in the MC question as the source of energy for the earth's water cycle. There was an apparent disconnect between the term radiation and solar energy, with students often associating knowledge of the tides and the influence of the moon's gravity with the water cycle, thus attributing energy input to the sun's gravity. This idea, that the Sun's gravity pulls the water, was reflected in the following response: *"I know the moon's gravity affects tides, so it would make sense for the sun's gravity [to have] some kind of effect as well."*

Some students also mentioned that "Wind moves the water" ($n = 11$) reflected in the response, *"From personal observation, I have viewed the water cycles from* *the wind."* This alternative conception was common in responses from students who selected the Wind's motion in the MC question, indicating an inaccurate association between the physical movement of liquid water within a body of water and the movement of water through the water cycle. It is apparent that, for these students, understanding of the water cycle is superficial. This assertion is supported by other "wind" responses that described the wind moving moisture in the atmosphere, e.g., "*The way the wind currents blow determine where it will rain and the wind cycle moves the water around the globe.*"

A few students answered that the rotation of the Earth causes the water cycle or the Sun's radiation gives power for the water cycles. These conceptions were often elicited from students who chose option B or C, Sun's radiation or Earth's radiation, in the MC question. Even when students selected the correct MC choice, not all students provide scientifically correct reasons to support their choice. The alternative conception, Sun provides power to water, may imply difficulty in differentiating the terms power and energy for these respondents. Another alternative conception, Earth's rotation causes the water cycle, showed that they apparently connected physical movements to the energy source.

In the EA content topic question addressing the energy source aspect (Q6) asking an example of the use of an alternative energy source, the rate of correct responses was similar to Q1 in the EE content. Less than half of the students (n = 33, 38.4 %) answered correctly regarding an alternative energy source in the EA content, identifying a solar cell as an alternative energy source. Among the incorrect responses, many students' conceptions about alternative energy sources seemed to be restricted by the term *alternative*. The students' common incorrect responses were classified with the code; alternative energy is supplementary or alternative (n = 17). These responses identified alternative energy as simply different from conventional energy sources, such as electricity, or as a supplement, as with using electricity with gasoline in a hybrid car. A few students who selected option D, identifying a hybrid car as using an alternative energy source, associated alternative energy to energy costs, answering that alternative energy reduces the cost of electricity or gas (n = 2). One student also indicated that alternative energy creates energy from nothing, failing to consider energy conservation. Noticeably, some students who selected the right choice for the MC question equated alternative energy and natural energy (n = 18). Equating alternative to natural reflects the connotation present in the non-scientific use of the scientific terminology, e.g., "*The solar cell gets natural energy from the sun.*" Equating alternative energy to "natural" or "nature" was not only applicable to solar energy, but also to the other energy sources not considered alternative energy sources, indicating a lack of understanding of the scientific term *alternative energy source,* despite correctly answering the multiple choice question.

Conceptions about Energy Transfer

The energy transfer question in the EE content (Q2) asked students how energy transfers between organisms in a food chain. More than half of the students who responded to the OE question demonstrated the scientifically correct reasoning that released chemical energy transferred along the food chain (n = 46, 53.5%). Nevertheless, several alternate conceptions were evident. Several students' answers inaccurately associated the energy transfer in the chain with heat, indicating that the Sun's heat is transferred as calories since food contains calories. This represents a limited understanding of the scientific use of the term calories as opposed to the use of the term in everyday language. This alternative conception was consistently found from students who chose one of the incorrect options in the MC question. Some students who chose option E, energy of motion, exhibited the belief that since living organisms can move, kinetic energy is transferred along the food chain (n = 7). This reflects students' intuitive understanding of energy forms without taking into account energy transfer processes through molecular changes. Some students also indicated that each organism produces a different kind of energy since their food types are different, so a different type of energy is found at each level. These students inappropriately equate energy with matter. This alternative conception was generally associated with MC option B or E, which implies that although they chose a certain form of energy, they didn't provide a relevant reason to support their choice. Instead, they associated energy forms with food types. A few students answered that the Sun's light is used up as energy moves through the chain. These students selected either heat energy or energy of motion are transferred along the food chain, indicating that they didn't understand energy transfer.

Responses within the EA content (Q7) asking what happens to energy as a hydroelectric station generates electricity, showed that some students hold the alternative conception that energy is generated by using up matter, equating energy to matter. This alternative conception was reflected in the following responses: *"A chemical or liquid is being converted into energy,"* and *"Water is used to create electricity."* In these cases, students explained that water is converted directly into potential energy or electric energy in a hydroelectric plant. Surprisingly, this conception was mostly found from students who chose the correct MC choice. Potential energy is converted into electric energy, for the MC question. One student who chose "Chemical energy is converted into electrical energy," showed this alternative conception mentioning, "Water (chemical) is converted into electric energy." Some students also exhibited the alternative conceptions that energy is created by the hydroelectric station. In these responses, students indicated that potential energy or heat energy provides the energy to power a machine, which in turn creates energy. A few students were confused by the term hydroelectricity, specifically the "hydro" prefix. These students chose option B, Heat energy is converted into electric energy, and stated that they knew that hydrogen is a gas, associating hydro with heat in a hydroelectricity station. Less than half of the students answered this question correctly (n = 27, 31.4 %).

While the findings from these two items showed different alternative conceptions across science content topics, we found two consistent alternative conceptions across items; energy is used up and energy is matter.

Conceptions about Energy Degradation

Only ten students demonstrated scientifically correct reasoning for the energy degradation item (Q3) asking what energy is available to the last consumer in a food chain. Among students who selected option A, which indicates that all of the energy from previous stages in a food chain is available to the last consumer, many of them shared the conception that the top of the food chain gains all of the energy from all of the organisms below it (n = 29), e.g., *"[The wolf] is at the top of the food chain, therefore he absorbs everything accumulated to that point."* Such responses were coded as "No E degradation along the food chain." This result indicates a fundamental misunderstanding of energy transfer, specifically the belief that there is no degradation across food chains or webs. Some students who chose option E, the correct choice, also showed the alternative conception that "E is used up" (n = 19), e.g., "*Some of the energy will be used for life processes by the animals.*" These students identified that not all of the energy is passed on between levels, yet did not indicate an understanding that energy is degraded during the transfer. Instead, they indicated that organisms use up some of the energy that they gained in their life processes and thus the apex predator receives a reduced amount of the initial energy. Some who chose the correct choice also indicated that the number of organisms determines the amount of energy within the system. This reflects the alternative conception that matter is equal to energy, "E is matter" (n = 8, 9.3 %) and is related to students' misunderstandings of populations and carrying capacity in ecosystems. Again, we found that although students chose the correct option in the MC question, it doesn't necessarily mean that they understand the concept correctly, rather they posit the alternative conception to support their choice. When investigating students' understanding of energy degradation in a more limited system, students showed their lack of ability to apply energy degradation to a more specific situation (Q4). Q4 showed a picture representing an ecosystem consisting of a frog and a mosquito; a mosquito bit a frog and then the frog eats the mosquito. Q4 asked students how the total amount of energy of the system changed during this process. Many students who chose option A, energy is increased, revealed their alternative conception that "E(energy) is created" (n = 30, 34.9 %), which was reflected in responses such as, *"The system's total energy increases upon eating mosquitoes" and "The frog makes energy."* These students seemed to assume that a body will create energy by eating food, so the amount of energy after eating will be greater than the initial amount of energy of the system. Other responses also included the alternative conception that there is no degradation when going through a food chain consisting of two organisms. These responses were coded as "No E degradation along the ecosystem" and found mainly from students who chose option C, indicating that energy will be conserved since there is no energy degradation. This response was also found from students who selected the option A, implying that they apparently overlooked energy degradation in the ecosystem. Among students who selected option B (the amount of energy is decreased), some explained that since E is used up (n = 11) in eating, so the amount of energy is decreased. One students who chose the option A tried to connect the size of the organisms' bodies with the amount of energy, and another student who chose option C mentioned that the organism had not changed so the amount of energy remains same, reflecting the conception that matter is equal to energy. This is also reflective of students' limited understanding of the complex nature of food chains, particularly in considering situations where there isn't a simple, one-way, linear progression through the chain.

Q11 related to the relationship between energy and biomass, which asked why the amount of biomass decreases at higher trophic levels. Some responses associated with MC option D (because there is a loss of energy from producers to consumers) included the alternative conception that "E is used up" in each organism (n = 13). Similar to the Q4 responses, these students seemed to believe that a loss of energy occurs because organisms use energy to eat food or survive, but not from energy degradation. Another alternative conception was founded in the idea that matter is equated with energy (E is matter), specifically that the amount of grass in the question was greater than the number of animals, so the grass has more energy or that the organism size decides the amount of energy. This conception was found in responses for all four options in the MC question, implying that students attributed the biomass pyramid to the available matter not to the amount of energy. Two students' responses indicated that energy in the upper levels is less useful, so lower levels include more energy. This alternative concept emerged in Q8 as well.

Questions regarding energy degradation in the EA content topic revealed that students lack understanding of the term energy efficiency. Q8 prompted students to identify why alternative energy sources cannot have 100% energy efficiency. Many respondents recognized that alternative energy sources were not 100 % efficient, but attributed this to environmental factors affecting energy availability which supported their selected option A or B, the inconsistency of availability of various resources such as daily and seasonal variations or variations by locations. These responses were coded, "The amount of input E decides that of output E." This code was reflected in the following responses: *"It is not always sunny or windy, therefore it depends on the right weather and climate for an alternate source to work,"* and *"Because an alternative energy source such as water is not readily available in places like the Mojave Desert or Arizona because they are desert and water is in short supply."* Three students who chose option D, some energy is transformed to a less useful energy form, demonstrated the alternative conception that alternative energy inherently cannot be as good as conventional sources, and two other students who chose option A also posited this idea. Three students who chose option C, alternative energy is transformed into a more useful energy form, answered that the type of energy determines the amount of energy, with responses coded as, "Useful E has more E," reflected in the responses: *"Alternative energy is transformed into a more useful energy form."*

When asking students about the same energy aspect within a more specific system, a wind turbine (Q9 asking the amount of input of the wind's kinetic energy into a turbine compared to the amount of output of electric energy), 12 students answered correctly. Incorrect responses presented several alternative conceptions. Several students who selected option B or C, input is less or more than output, indicated that energy is used up in spinning the rotor. Many students who selected option A, same amount of input as output, indicated that there is no degradation while the wind's kinetic energy is transferred to electric energy by spinning the rotor, failing to recognize the degradation of energy. Some students who chose option B also held the idea that the output energy is greater since the turbine generates energy, not recognizing the initial energy present in the wind, "E is created by a turbine." A few students showed the alternative conception that energy is matter, reflected in the responses that, *"Wind is less dense than a turbine, so it contains less energy,"* and, *"Wind has more E since air is a lot."* These responses were associated to their MC choices indicating that either the input energy is less or more.

In summary, in both EE and EA content topics most students failed to apply the energy degradation concept. While there were different emerging alternative conceptions across the two science content topics, several alternative conceptions, including "E is created" through eating or by a machine, "Energy is matter," "Energy is used up," and, "Useful E has more E," were commonly exhibited across the two different content topics.

Conceptions about Energy Conservation

In response to both EE and EA items, a number of students correctly provided the statement of the law of energy conservation (n = 20, 23.3 % for Q5 and n = 18, 21.0 % for Q10). Q5 showed the same picture as Q4, an ecosystem consisting of a frog and a mosquito, and asked students how the total amount of energy of the system including the surroundings changed as the mosquito was eaten by the frog. The majority of these students merely recalled the law of energy conservation without any explanations to support their responses. Only a few students provided reasoning for their choice by applying the energy dissipation aspect. Q5 prompted students to consider energy transformation in an ecosystem including surroundings. The most frequent response equated eating to earning energy in the body and was coded as "E is created" (n = 30). Q10 prompted students to consider both a wind turbine system and its surroundings as the turbine generates electricity. The most common response to this prompt indicated that "E is created" by the turbine, so the total amount of energy increases, which supported their selected option A in the MC question (n = 26). These two types of responses suggest the alternative conception that energy is created for use. Across the two items, no degradation in the system, coded "No E degradation," was also commonly detected. When students selected option A, the total amount of energy increases, in the Q5 and Q10, some demonstrated the conception that there is increasing energy without energy degradation. We also found a common alternative conception across the two items coded "E is used up." These responses were found to support their choice to the MC question, i.e., the total amount of energy decreases, implying that these students thought energy is used up in processes like eating or spinning a rotor, thus decreasing the total amount of energy. Responses showed that some students equated matter and energy in their responses similarly to responses from Q4 and Q9.

Several students showed alternative conceptions specific to individual content topics. For example, students responded that the amount of input wind is not predictable, so energy cannot be conserved, coded "The amount of input E decides that of output E", in Q10. This is similar to the degradation question regarding energy efficiency and reflective of superficial understandings of energy conservation. One student in Q5 responded that, "*[The] mosquito dies, so no energy in it.*" In this response, the student thought that dying mosquitoes do not contain energy, which reflects the "E is vitality" alternative conception.

In summary, many students showed various alternative conceptions in the energy conservation items across the two different content topics; energy is not degraded, energy is used up, energy is created by eating or through a machine's work, energy is matter or that only living things have energy. The contradictory answers could suggest that many students have difficulty in applying the idea of energy conservation beyond simple recall. Some students' responses included statements of energy conservation, but provided no additional explanation. They could have memorized this law or may have seen it applied in classes or textbooks, but were unable to demonstrate a deeper understanding.

Discussion and Implications

The main purpose of this study was to examine students' conceptions about energy across various energy aspects in different science content topics within the environmental science discipline. In the following sections, we will summarize and discuss our findings from this study. As seen in the table 1, our finding showed a variety of alternative conceptions associated with specific content topics, especially when items addressed energy source/form aspect, and commonly attainable alternative conceptions across different content topics, especially when addressed energy degradation and conservation aspects. The findings imply that college students' alternative conceptions in energy source/form showed more content topic-specific characteristics while their alternative conceptions in energy degradation and conservation were more generally applicable across different content topics.

Students' Content Topic-Dependent Alternative Conceptions

Several students' content topic-dependent alternative conceptions were revealed in the energy source/form items. For example, many students tended to attribute the water cycle to exerted force on the water. There was an apparent disconnect between the term radiation and solar energy indicated, with students often associating their prior knowledge of the tides and the influence of the moon's gravity with the water cycle, thus attributing energy input to the sun's gravity. For students indicating that the wind was the primary energy source, the inaccurate association between the physical movement of liquid water within a body of water and the movement of water through the water cycle indicates that understanding of the water cycle is very superficial. This particular alternative conception may be due to misunderstanding of the common textbook diagram depicting the water cycle, which may cause an exaggerated sense of the importance of the wind as an energy input. These diagrams often show evaporation over a large body of water forming clouds, which are blown inland by the wind and release moisture via precipitation. Another possible explanation indicated within some student responses relates to the indication that water is moving to the atmosphere and back to the ground. Students seemed to associate the source of movement of the water with force or power physically exerted on the water. It is apparent that these students formed and held naïve conceptions based on their interpretation of observed phenomena throughout their lives.

In the case of the EA energy source/form item, students' understanding of alternative energy source/form showed a limitation in defining alternative energy sources/forms. According to Çoker, Çatlioglu, and Birgin (2010), students often have difficulty explaining renewable energy sources, and they do not clearly understand these energy concepts. This study also found that many students did not recognize alternative energy sources, and showed their restricted understanding of the term alternative, which brought them to the conclusion that "alternative" refers to "supplementary."

From energy transfer and degradation items, we also found some alternative conceptions attached to specific science topics. In EE, two noticeable alternative conceptions were identified. First, the Sun's energy is stored as calories, which represents a limited understanding of the scientific use of the term calories as opposed to the use of the term in everyday language. Second, transferred energy along a food chain is kinetic energy, which reflects students' intuitive understanding of energy form. This might be due to limited exposure to viewing the energy transfer process in terms of molecular changes in ecosystems. In EA, two other alternative conceptions were found. First, that alternative energy is not as useful as conventional, so the amount of energy is ascribed by the quality of energy. Second, the efficiency of alternative energy is attributed by intermittent input energy. This, again, indicates a lack of understanding of energy efficiency, in which students consider only input energy as opposed to comparing output to input, without taking into consideration of energy degradation.

Students' General Alternative Conceptions

Several common alternative conceptions were found in energy transfer and degradation. Students' conceptions about transferring energy through a food chain was primarily limited to a superficial understanding that organisms higher on the chain obtained energy by consuming organisms lower in the chain. In a variety of ways, students appear to see the apex predator as having advantages like gaining the most energy. Findings also indicate that students have great difficulty in applying energy transfer and energy degradation to a specific ecosystem, an alternative conception revealed in EA content as well. Several other common alternative conceptions were consistent across the two different content topics: energy being used up, energy being created, equating energy with matter, and useful energy containing more energy.

The types of students' alternative conceptions in the energy conservation aspect were similar to those in energy degradation, indicating that understanding of these aspects is closely related. Similar to the findings of Chabalengula, Sanders, and Mumba (2012), this study found that when students applied the law of energy conservation, they generally relied on simple recall of the law without any reasoning or evidence to support their assertion. Goldring and Osborne (1994) presented that even when students could recall accurately concepts related to energy, like the law of energy conservation, understanding of the concepts was limited and many students were not able to apply the principle in solving simple problems. This result suggests that teaching the law of energy conservation should include a transition from presenting examples of energy conservation to providing opportunities for students to find evidence to prove how energy conservation is established and applied in a variety of scientific phenomena.

It became apparent that students have more difficulty in understanding energy aspects in a specific ecosystem than in general theoretical examples, as with a food chain. Some students' responses indicated the alternative conception that matter is equivalent to energy and is related to students' misunderstandings of populations and carrying capacity in ecosystems. This result suggests that it is necessary to give more opportunities for students to apply scientific concepts in examples of specific ecosystems.

Alternative conceptions stemming from confusion between energy related to science terms and scientific versus non-scientific definitions of terms were very common among student responses across all energy aspects and science content topics. Most responses regarding alternative energy reflected the influence of the use of the term "alternative" in the media and everyday/social language on students' scientific understanding of the concept. Phrases such as "used up" or "created" were not used in scientifically correct ways when talking about energy conservation and were common amongst student responses. It is evident that the non-scientific use of these terms impacted the students' conceptions of energy.

This study has revealed various alternative conceptions about energy that were newly identified or similar to those identified in previous studies. The findings from this study help recognize strengths and weaknesses of student understanding of the energy concept in the environmental science discipline at the culmination of their K-12 experience to better develop science instruction and curriculum for college as well as K-12 levels.

We note limitations to our study that could be investigated in future research. First, this particular study doesn't include student interview data. Follow up research including extended interviews to further explore the alternative conceptions identified in this study may be illuminating. Second, this study includes two science content topics related to the energy concept in environmental science, so there is a need to broaden science content to include topics such as climate change. It will be worthwhile to explore the specific alternative conceptions uncovered through this study individually and in greater depth to further illuminate their origins and the best ways to address them in science curriculum.

Disclosure statement

No potential conflict of interest was reported by the authors.

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