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Development of the ecological concepts of energy flow and materials cycling in middle school students participating in earth education programs

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ABSTRACT

This paper focuses on the development of understandings of the ecological concepts of energy flow and materials cycling of middle school students. It is based on a qualitative analysis of individual interviews with 6 students in an urban area of the southern US conducted every year over a 5-year period in 2004–2008, starting in grade 4 and finishing in grade 8. In addition to their formal education, all of the students participated in three outdoor earth education programs (Earthkeepers, Sunship Earth & Sunship III) over a 4-year period. Specifically, the study analyzed what misconceptions connected with energy and matter emerged and how students' conceptual understanding developed over time. In addition, it discusses the possible effects of educational programs on participating students. The study demonstrates the non-linear process of conceptual change, constrained by a few persistent students' misconceptions. The study also discusses potential implications for the practice of outdoor educational programs.

1. Introduction

1.1. Framing the study

The development of ecological conceptual understanding is considered as one of the goals for both environmental education (Hungerford, Peyton, & Wilke, 1980; North American Association for Environmental Education, 1999, 2000North American Association for Environmental Education, 2000North American Association for Environmental Education, 1999, 2000) and science education (Quinn, 2012; The Next Generation Science Standards for States, 2014). For environmental education, these understandings are seen as necessary to achieve the ultimate goal, behavior change to lessen people's impact on the planet (Hungerford & Volk, 1990). While it has been shown that ecological knowledge alone does not promote responsible environmental behavior, it is usually considered as an important indirect driver (Hungerford & Volk, 1990; Kukkonen, Kärkkäinen, & Keinonen, 2018; Roczen, Kaiser, Bogner, & Wilson, 2013). While some ecological concepts are typically included in science courses, environmental education is not often a fundamental component of education in school classrooms. Often, however, it is more frequently conducted in outdoor settings as field trip experiences.

Among the specific concepts students are to learn, energy and matter have special importance. It might be argued that both concepts are crucial not only for promoting students' scientific literacy but also from the perspective of students' everyday behavior (Ntona, Arabatzis, & Kyriakopoulos, 2015; Rizaki and Kokkotas, 2013; Schnittka & Bell, 2011). Particularly, this need is supported by the necessity to act responsibly to mitigate the effect of upcoming climate changes.

According to the The Next Generation Science Standards for States (2014), fifth grade students should be able to describe the movement of energy in food chains and realize that energy in food comes from the sun. Concerning matter, students should understand that matter is made of very small, invisible particles, that the total weight of matter is conserved, and that matter moves among plants, animals, and the environment (The Next Generation Science Standards for States, 2014).

As Rizaki and Kokkotas (2013) describe, while the concept of energy may be considered as a very basic precondition of students' understanding of environmental issues, it also requires abstract thinking. In light of this, the process of its development is both demanding and crucial for environmental learning.

The present study focuses on the process of conceptual changes in elementary school students' understanding of energy flow and matter. Specifically, it focuses on misconceptions emerging over a 5-year span and on the possible role of outdoor educational programs in this process.

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1.2. Overview of conceptual change theories

Although the process of development of students' conceptual understanding in terms of ecological concepts connected with energy or matter has been a subject of many papers, it still remains a matter of investigation (Abdullah, 2015; Çinar, 2016; Kiray, 2016; Megalakaki and Thibaut, 2016; Saglam & Ozbek, 2016). As Park and Liu (2016) and Çinar (2016) found, students often have difficulties with understanding these concepts or are unable to apply them in specific situations.

One of the main reasons for difficulties is the nature of the process of students' development of scientific concepts. There is a high level of agreement that children are not passive learners but active constructors of their own conceptual understanding of the world. In the process, they develop their naïve theories, which often contflict with scientific knowledge. From this constructivist' perspective, learning may be interpreted as a process of conceptual changes (Butler, Mooney Simmie, & O'Grady, 2015; Duit & Treagust, 2003; Hallden, Scheja, & Haglund, 2013; Pine, Messer, & John, 2016; Posner, Strike, Hewson, & Gertzog, 1982; Zhang, Chen, & Ennis, 2017).

Conceptual change is one of the central ideas of science education and has been analyzed from different perspectives (Chi, 2013; diSessa, 2014, 2017). Contrary to older theories assuming that the original understanding can be radically replaced by new ideas, more recent approaches highlight the gradual process of conceptual change. As a result, after being exposed to new experiences, students do not completely abandon their alternative frameworks but rather modify their original beliefs, often changing some parts of them while retaining others (Abdullah, 2015; Duit & Treagust, 2003; Saglam & Ozbek, 2016; Vosniadou, 2013).

This processes of developing of scientific concepts are still a matter of debate among researchers. One of the key questions is how coherent or fragmented students' alternative theories are. According to Vosniadou (2013), students tend to make "synthetic models", mixing the "old" with the "new" to one framework theory. While the synthetic models may be able to provide good explanations of some of phenomena, they fail for others, and as a result, they create misconceptions (Hallden et al., 2013; Vosniadou, 2013).

Other authors offer a different perspective (diSessa, 2014; 2017; Hammer, 1996). diSesa (2013; 2014, 2016) argues that students' knowledge consists of a set of very elemental beliefs based mainly on experience and common sense, called phenomenological primitives, or p-prims. P-prims are not necessarily wrong; they may provide a plausible explanation in a particular context, while they may be inadequate beyond its scope. In light of this, sound instructional strategies try not to force students to alter their mental models as a whole but rather start with the identification of p-prims in play, encouraging the ones plausible for a learning concept while challenging the others.

The nature of students' misconceptions presents another theoretical issue. According to Chi (2008), 2013), there are different types of misconceptions. While some inaccurate misconceptions can be easily refuted, others come from children's flawed mental models, incorrect categorization of the concept, or a missing mental category (schema). In light of this, to alter different misconceptions, different teaching strategies are needed.

1.3. Students' misconceptions of energy

The concept of energy is often described as confusing and difficult to learn (Dalaklioğlu., Demirci., & Şekercioğlu., 2015; Delegkos & Koliopoulos, 2018; Rizaki & Kokkotas, 2013). Students tend to associate energy with a lot of different meaning including force, fuel, liquid, causal factor, etc. and, as a result, they do not use it for explaining natural phenomena (Rizaki & Kokkotas, 2013). This ambiguity is the source of many associated misconceptions. For example, according to Butler et al. (2015), students often assume that animals at the top of the food chain have the most energy, that energy is not conserved, or that food chains do not involve producers.

According to the idea of learning progressions, students' understandings seem to progress through a set of stages (levels), with the first level the least and the fourth the most scientifically accurate understanding. According to Jin and Anderson (2012), students' understandings of energy at level 1 rely primarily on informal sources of knowledge (e.g., personal experience). For example, students at the lower levels often believe that energy is connected with living world things, e.g., living things grow and so have energy while dead things do not have life and so do not have energy. At level 4, they are able to identify forms of energy or describe how chemical energy is transformed.

1.4. Students' misconceptions about matter

The concept of matter provides another area of students' misconceptions. Students often perceive matter as continuous and reject the idea that it consists of elemental particles (Adadan, Irving, & Trundle, 2009). One widespread misconception is that atoms are not the basic constituents of matter but rather molecules are embedded in matter (Wiser & Smith, 2013). This misconception is often unfortunately supported by simplified illustrations in textbooks. Students also have difficulties with grasping the particular nature of non-solids and with understanding the concept of conservation of matter. According to Smith and Wiser (2013), young children's view of matter is based on their perceptions; they do not understand that air is matter. Some students also believe that some materials (e.g., air or water) exist between particles of matter (Adadan et al., 2009). When elementary school students generally accept that matter can be divided into small, invisible pieces, some of them believe that small pieces of matter, after being cut into even smaller pieces, disappear (Smith & Wiser, 2013). Similarly, students sometimes believe that the number and size of particles change when a liquid is vaporized, e.g. that the size of molecules depends on the temperature (özmen, 2011).

In addition, as Mohan, Chen, and Anderson (2009) identified, students may believe that plants and animals are governed by different mechanisms and are made of different materials than non-living things.

According to Smith and Wiser (2013), the concept of matter is closely associated with concepts of weight, density, mass, and material. Because of this, a reconceptualization of one of them cannot be possible without affecting the others.

While more theories explaining the process of conceptual change are in play, it is still not much clear how these changes develop over time. The possible impact of outdoor educational programs on facilitating conceptual changes presents another not adequately studied area. Positive effects of an outdoor educational program on students' ecological knowledge have been found by Bogner (1998); Bogner and Wiseman (2004); Manoli et al. (2014) and Cincera and Johnson (2013). In light of this, it can be assumed that outdoor educational programs may provide an opportunity for students' conceptual changes. However, all of the above-mentioned studies evaluated the effect of outdoor programs in a relatively short time span (usually a few weeks) after their implementation. It is not clear either how students' ecological understanding facilitated by their participation in an outdoor program develops over a longer period of time or how repeated exposure to outdoor programs may effect this process. Particularly, it is not clear how students deal with scientific concepts presented by the program; if they abandon their original naïve theories or rather make synthetic models mixing the "old" with the "new", and generally, providing they are repeatedly exposed to the scientifically correct explanation of the concepts, how this cumulative learning experience influences the process of conceptual change.

These issues of students' misconceptions of ecological concepts and how students' understandings of these concepts develop as they participate in earth education programs are investigated in this study.

2. Methodology

2.1. The conceptual framework of the research

The present study focuses on the development of elementary school students' conceptions of energy and matter over a time-span of five years. Specifically, it focuses on the following questions:

- What misconceptions connected with matter and energy emerged in a five-year time-span?
- How did the students' understandings of the concepts change over time?
- How are students' conceptual understandings associated with their participation in earth education programs?

The study was conducted with a small sample of six students participating in earth education programs from grade 4 (year 1) through grade 8 (year 5). All the students were interviewed on several occasions during that time.

2.2. Sample description

For this study, six students (three boys and three girls) participating in three earth education programs (Earthkeepers, Sunship Earth, and Sunship III) were selected. The sampling criteria were to get a heterogeneous group in terms of gender, ethnicity, and a range of initial levels of environmental attitudes measured by the 2-MEV instrument (Bogner & Wiseman, 2006). All were ages 9 or 10 in the first interview.

Participants are all from the same ethnically diverse school in a large city in the southern United States. In year 1, all of the students in one of the classes that were scheduled to participate in the Earthkeepers program were invited to participate in the study. Of the 20 who assented (and whose parents consented), six were selected to get the heterogeneous group described above.

2.3. Intervention

All of the respondents participated in three earth education programs (Earthkeepers, Sunship Earth, and Sunship III). Earth education is a specific approach in environmental learning, highlighting the importance of well-designed outdoor educational programs focused on developing students' ecological understandings, values, and behaviors. The goals of the program are to help participants build understandings of four ecological concepts (energy flow, materials cycling, interrelationships, and change), develop positive feelings for the natural world, and make changes in their behaviors to lessen their impact on natural systems and processes. The programs are offered by different program centers in several different countries (Van Matre & Johnson, 1988; Wohlers & Johnson, 2003; Van Matre, 1990).

For the present study, the Earthkeepers program in year 1 took place at a day use site outside of a city in the southern United States. Students came to the site by school bus each in the morning each of the three days and returned home each afternoon. The Sunship Earth in year two and the Sunship III program in year four took place at a residential center outside of the city. Students arrived by a school bus on the first morning and spent two nights, leaving after lunch on day three.

The ecological concepts in this study (energy flow and materials cycling) are two of the four concepts taught in these earth education programs, along with interrelationships and change (Van Matre, 1990). While the specific student activities and components of the concepts emphasized differ across the programs, the central ideas of the concepts are consistent as are the overall teaching strategies.

In each of the three programs in this study, the ecological concepts are taught in outdoor, participatory activities presented as part of the multi-day earth education programs for children ages 10–11 (Earthkeepers), 10–12 (Sunship Earth) and 13–15 (Sunship III). In all of the programs, the activities are framed (see Kang, Windschitl, Stroupe, & Thompson, 2016) as meaningful concepts relevant to students' daily lives.

The instructional approach was based on the Inform-Assimilate-Apply (I-A-A) Learning Model (Wohlers & Johnson, 2003; Van Matre, 1990). The model builds on the idea that learning requires much more than just taking in information. Before the programs, students are asked to recall what they know about the ecological concepts with their teachers. During the program, the activities begin with reading a brief description of the concept in a student booklet (Inform). Next, they participate in an activity or activities that help them experience the main ideas of the concept in concrete ways in the natural world (Assimilate). Finally, they find an example of the concept in nature and draw/write it on an application page of the student booklet, and then they explain their example to one of the leaders (Apply). Further application later on in the programs involves seeing the concept in action both on-site and later back at school and home.

The programs also used several methods recommended by different authors, such as educational games (Al-Tarawneh, 2016), visual representation (Rizaki & Kokkotas, 2013) and drama education (Abed, 2016). The programs also meet recommendations for developing scientific understanding in outdoor programs defined by Rickinson et al. (2004); Neill and Richards (1998) and Erdogan, Uşak, and Bahar (2013), specifically program length, instructional clarity, and connection with school curricula. The programs also meet quality criteria defined by The Real World Learning (2015), specifically in terms of value communication, transferability (linking the knowledge learned in the program with broader perspectives and every day's students' lives), application of overlying frames, and utilization of direct experience with nature.

On the other hand, the instructional strategy does not reflect other recommendations presented by conceptual change literature. While teachers are meant to prepare students for their conceptual learning, few guidelines are given to assess students' apriori knowledge. As a result, students' naïve theories or already existing misconceptions may not be taken in consideration (Butler et al., 2015; Duit & Treagust, 2003; Kang et al., 2016).

The effectiveness of this approach in terms of improving students' conceptual understanding has been demonstrated (Cincera & Johnson, 2013; Felix & Johnson, 2013; Manoli et al., 2014). However, how participants' understandings develop over time as they participate in multiple programs has not yet been studied.

2.4. Data collection and analysis

Individual, semi-structured interviews were conducted five times from 2003 to 2008, once each year, at the students' school. The timeline of the interviews can be seen in Table 1. In year 1, the first interview was conducted before the students took part in the first program, Earthkeepers. The second interview took place before students participated in the second program, Sunship Earth. No program was planned for year 3, but an interview was still conducted. In year 4, the interview was conducted after the third and final program, Sunship III. The final interview was in year 5, one year after the third program.

Table 1
Timeline of Programs and Interviews.

Year	School Grade	Interviews	Program
1	4	February 2004 (pre-program)	March 2004 - Earthkeepers
2	5	November 2005 (pre-program)	April 2005 - Sunship Earth
3	6	April 2006	No program
4	7	April 2007 (post-program)	January 2007 - Sunship III
5	8	February 2008	No program

Table 2
Examples of questions asked in the interviews.

Main concept	Properties of the concept	Questions
Energy flow	Source of energy	Where do plants (animals, humans) get their energy?
	Using energy	How do living things use energy?
	Food chains	Are there more plants, herbivores, or carnivores in the world? Why is this the case?
Matter	Atomic structure	What is everything made of?
	Recycling of matter	What happens to an animal body when it dies?
	Conservation of matter	Imagine a box with soil in the bottom and an apple resting upon the soil. Nothing can get in or out of the box. I weigh the box with the soil and the apple, leave it for two years and then weigh it again. What will have happened to the apple? After two years, will the box weigh more, the same, or less than it did at the start?

All of the respondents were asked a set of open-ended questions and given problem-based tasks assessing their level of understanding of the associated concept. Each of the questions assessed a specific property of one of the main analyzed concepts (energy flow, matter). Examples of questions can be seen in Table 2.

The first author conducted all of the interviews. The interviews were audio-recorded and transcribed. The analysis applied a combination of open coding methods and two pre-determined general categories (knowledge of energy and knowledge of matter). For all of the excerpts corresponding with one of these categories, initial open codes paraphrasing a respondents' idea were used (i.e., "not sure if molecules are alive", "molecules and atoms are of microscopic size") (Saldana, 2015). During analysis, the authors made memos recording their on-going reflection of the findings (Charmaz, 2006). All the excerpts were further sorted according to their codes. While the two authors analyzed data separately, they also continuously compared their analyses and discussed ideas based on their memos to achieve consistency of the analysis. To explain the understanding of conceptual changes emerging in students' responses over time, the authors wrote a storyline for each of the respondents. All of the storylines were discussed by both of the authors.

2.5. Limitations

As the sample is limited, the findings cannot be generalized and their findings do not represent either US population or all of the participants of the programs analyzed, rather they provide insight into the way students construct meanings of ecological concepts of energy and matter. As the interviews were the only source of data, the study may miss perspectives that other, additional methods (e.g., conceptual maps) could provide.

Furthermore, while one of the original reasons for the analysis was to understand the process of conceptual changes facilitated by participation in earth education programs, the described changes cannot be easily attributed to the programs but to a mixture of factors including the effects of school lessons, informal learning, students' socio-culture environment or maturation. As a result, the study should be interpreted as an analysis of a process of conceptual changes of students participating in earth education programs rather than an attempt to evaluate the applied instructional strategies.

For the analysis, both of the authors remained open to all of the above mentioned theoretical perspectives explaining the process of conceptual change to avoid "forcing" the qualitative data into pre-determined theoretical categories. However, such an approach could be interpreted also as a limitation of the study, as it compromises a potential benefit for testing a particular theory and providing a more in-depth theoretical background for its analysis.

3. Findings

3.1. Students' understanding of energy flow

In the first year, before participating in any of the programs, participants held some common misconceptions about energy. For example, T2 stated that people get energy not only from food but also from drinking and exercising. This conflates different definitions of energy, combining the ecological concept of energy with the everyday use of the term to indicate how one feels, i.e., full of energy. This was common among the participants in year 1, prior to participating in the first program, and was less prevalent in later years.

In addition, in year 1 when discussing where plants get their energy, T2 used the term energy when he seemed to mean food.

> The producers make their own energy, like the sun and the water, and they're usually plants. (T2, Year 1)

In this statement, he seems to understand that green plants (producers) make food and need sunlight and water to do that. The next year, his understanding changed, becoming more complete. He realized that plants get their energy from the sun. He was also aware of humans' position at the food chain. Both of these ideas were taught in the first program in the activity Munchline Monitors, focused on energy flowing from the sun through green plants and on to plant eaters and animal eaters, including humans. In the third year, his explanations became more specific. He mentioned the concept of photosynthesis, which was taught in the second program in the activity Food Factory in which participants enter a giant leaf to create food molecules using representations of air, water, and sunlight energy. He was able to explain why light, water, and energy are needed. Additionally, he mentioned the term "chloroplast". In the final year, his understandings became more complete and clear.

Similarly, T20 was not sure in year 1 what the sources of energy for plants are. While he correctly assumed this is the sun, he also mentioned soil and water as the other sources. It is clear he did not differentiate between "needs" and "sources of energy", as he also commented that:

> We get it [energy] from food, water, and then we need sun. And the air. (T20, Year 2)

In the third interview, he was aware of the photosynthesis concept taught in the second program, although he did not know the formula, which was not taught in the program but was presented in the classroom later in the year.

> And that involves sugar and water and energy and sunlight and they turn – there was an equation we had to do in science but I forgot. You have to like – there's a – you know, and then the sunlight turns it into sugar… (T20, Year 4)

Although students' understandings of the food chain improved over the years, there were still some uncertainty and alternative theories. In the first year, T12 interpreted the food chain as a system controlled by humans. In the same time, she misinterpreted the food pyramid concept:

> Q: Let's say you go into the forest and there are these plants there, and the rabbits like to eat those… and there are foxes that like to eat the rabbits. Which do you think there would be most of in the forest, more plants, more rabbits, or more foxes?

A: Plants. Wait, it's either rabbits or plants. I can't decide between those two.
Q: So foxes would definitely be the least?
Because there's not a lot of foxes, and we use foxes for different things. (…) Mmm, they're probably not be a lot of rabbits and so they probably can't get their food and so they might die. (T12, Year 2)

The next year, after participating in the first program, she more fully understood the food chain concept. She knew where plants, animals, and human get energy and why they need it. Starting in year 3, she was able to explain a food chain and was aware of photosynthesis even if she did not really understand how it works. In year 4, however, she changed her ideas again, stating that animal-eaters would be the most prevalent in the ecosystem. When responding to the same question, she appeared to work her answer through logically rather than applying what she learned about ecosystems and energy in living things.

A: Um, probably more animals that eat those animals…Because the animals, first they eat the plants, and so there's probably not gonna be that many plants because all those animals eat the plants…And then the animals that eat the animals, since they eat animals, there're gonna be fewer animals. (T12, Year 4)

Similar altering of more scientifically correct ideas to ones less supported by science emerged from an interview with other participants. T20 changed this concept two times. Originally, he stated that we could find the same number of the organism at each of its levels. In year 3, he correctly stated that the plants are most common in an ecosystem, matching what was taught in the first program, but in year 4 said that it might depend on the type of the ecosystem, when water scarcity may influence the proportion between plants, plant-eaters, and animal-eaters:

"It would be … the last one in the food chain, maybe, because there's always predators and in some cases, there's no plants, or, like a desert…There'd be probably more plants 'cause there's a lot of water." (T20, Year 4).

Other participants (T5, 13, 14) initially based their (correct) explanations on their own observations, stating we see many more plants that we do animals. However, as they tried to replace their observation by logic analysis in the following years, they came to differing conclusions. T13 assumed plants and animals should be equal as they eat each other (Year 5), while T14 and T5 argued there would be more animals as they eat plants (Year 2). For T2, we can see the clear shift from equal numbers in Year 1 to a more accurate understanding in the following years.

3.2. Students' understanding of matter

As with energy flow, participants described a range of alternative and scientifically correct understandings. Their alternative understandings were primarily regarding the dualism of the living and non-living world.

For example, in the first interview, conducted before participation in any of the programs, T20 stated that atoms are living things forming all of life. He was able to explain how water and air cycles work but refuted the idea that solid particles could be recycled. He was not aware that particles cannot disappear (the law of conservation of matter), explaining that part of a dead body may disappear if it is not eaten.

In the second interview, when asked about what things are made of, he presented the idea of living germs as the building particles of the world:

A: Yeah, and germs, like they never really stop moving, they go into people and animals and plants and air and water… (…)
Q: And are they in everything?
A: Yeah, they're everywhere. You can't see them. And they're like so small I can't squish em. They're really small. (T20, Year 2)

In the third interview, he was trying to balance the idea of living (germs) and non-living (atoms) particles as he became aware that atoms recycle, but he was also keeping the concept of germs and minerals as the smallest thing. The recycling of molecules was taught in the first program in the activity Great Spec-tackle in which participants followed the paths of air, water and soil (mineral) molecules and in the second program in three activities, one each on air, water, and soil. In the fourth interview, his struggle to find a balance between both ideas led him to express a kind of dualism in which he believed that non-living things are made of non-living atoms but living things are made of living cells.

A: Oh, well like, non-living things like atoms and like stuff like that and living things such as cells.
Q: And do living things also have atoms?
A: Living things? No, I don't think. (T20, Year 4)

Other participants stated similar ideas. According to T2, while some of the molecules recycle, some do not (Year 2). In the next year (Year 3), he was able to reject this idea, explaining that everything is recycled. He was able to describe an application of this concept and its consequences. He was confident about atoms in both living and non-living things, even if was unsure about whether atoms are living. These ideas about molecules recycling and living and non-living things being made of atoms was taught in activities in both the first and second programs.

According to T5 (Year 2), living things are made of cells. In Year 3 when asked about molecules, she explained that living things are made of them, but she was uncertain if it is the case of non-living things, too.

When being asked about the origin of the atoms or molecules that do not recycle, participants provided various explanations. According to T13, water and air recycle but not materials in living things, as they were made by God (Year 1–3). In Year 4, she commented that even these material recycle but again refused this idea in the following interview (Year 5). Similarly, for T14, while some of the things are made of atoms, people are not (Year 4).

Another misconception expressed the idea that atoms may not only recycle through the material cycles but they may emerge from nothing, i.e. they may be created or born. For example, T5 recognized (Years 4 and 5) that everything is made of materials and that those materials are recycled, but she was not sure if some of the materials might also be created when something is born or grows.

Although the participants often came back to their original misconceptions or mixed them with new concepts, the influence of the programs was still visible. For example, T13 originally thought that water might be recycled in some cases but that air and materials in living things are not (Year 1). Those ideas changed after participation in the programs, all three of which included activities that demonstrate how air and water are recycled. T14 began with the idea that dead things disintegrate into the air (Year 1). After participating in the first program, he talked about how they decay to become part of the soil or are eaten by animals (Year 2), which he had experienced in the activity Great Spec-tackle, which teaches how the materials that living things are made become part of other living or non-living things when that plant or animal dies. In year 1, he had an understanding that water could be recycled but only in unique circumstances. After participating in the programs, he understood that water is recycled (Year 2). Also in year 1, he stated that materials that make up things are not recycled. After the first program, he understood that materials are recycled (Year 2).

4. Discussion

4.1. Students' misconceptions about energy and matter

A few misconceptions emerged from the interviews. The most common misconception connected with energy flow was a belief in other original sources of energy. This resembles the findings of Rizaki and Kokkotas (2013). Students also tended to misinterpret the food chain (Butler et al., 2015). It is obvious that students put an effort into balancing their personal experience with newly acquired knowledge. However, for some of the respondents (e.g., T5,13,14 for the food chain concept), the new knowledge seemed to be the source of misconceptions replacing the original, scientifically more valid naïve theory based on their own observation.

While students did not question the particulate nature of matter as a whole (Adadan et al., 2009), the alternative concept of the dualism of living and non-living world is clearly associated with a misunderstanding of atomic theory. As Abdullah (2015) suggested, the difficulties with grasping the concept of elemental particles are connected to their submicroscopic level. Due to the lack of direct experience, students may focus on a symbolic level of description of the phenomenon (i.e., to know the words like "atom" or "molecule"), while do not understand their nature. In the study, students often tended to link the concept of invisible elemental particles with the small objects they knew from their own experience, like "minerals" or "germs".

Similarly, as Mohan et al. (2009) found, students often assumed that different principles work for living and non-living things. Although such a framework is relevant up to some level, students mistakenly attributed these differences to the level of elemental particles, assuming living things are not built from atoms, as are non-living things.

The misconception expressing the idea that a matter may disappear reflects children' difficulties with grasping the conservation of matter law, mentioned also by Smith and Wiser (2013) and özmen (2011).

4.2. The process of conceptual changes

The findings suggest that while some of the students' misconceptions may be interpreted as the lack of proper knowledge (e.g., food chain) and could be relatively easily replaced by sound educational programs or formal education, others (e.g., dualism of the living and non-living world) are highly persistent and students struggle to keep them in play even after educational intervention.

These findings correspondent with Vosniadou (2013) theory of synthetic models. Rather than moving in one direction, the participants seemed to move back and forth, keeping some elements of their original frameworks and enriching them by new elements. Similarly to Saglam and Ozbek (2016), students tended to reinterpret their original framework rather than abandoning them and replacing them with new ones. As a result, while this progress does not contradict with the theory of gradual stages of conceptual development (Jin & Anderson, 2012; Mohan et al., 2009), it demonstrates that students' progress is not straightforward but constrained by persistent misconceptions.

In other cases, the original and scientifically accurate framework based on students' direct experience was replaced by an alternative one, supported by misguided logical analysis (e.g., food pyramid). Such a finding slightly contrasts with the gradual stages theory assuming the path from naive, non-formal, experience-based frameworks to more advanced (Mohan et al., 2009).

Another explanation of the process could be drawn from the theory of conceptual change. According to the Chi (2008) theory, while knowledge about food chains could have been easily assimilated, the belief in the dualism between living and non-living world may represent a belief in fundamental differences between these categories. Because of this, the new knowledge could not be easily assimilated because it calls for rejection of the original mental model (two worlds) and adoption of a new one (one world).

From the perspective of diSessa (2014; 2017) knowledge-in-pieces theory, the students' knowledge consisted of scientifically accurate P-prims (e.g., bodies of living and non-living things have different structure), that – while plausible up to some scope and level – led students to scientifically incorrect beliefs (living and non-living things consist of different elemental particles). To meet this problem, teachers could help students to understand the limits of the P-prim, without its direct rejection.

4.3. The impact of the educational programs

Although the students' conceptual development was far from being gradual or straightforward, the progress, particularly between year 1 and 2, was clear. After participating in the first program, Earthkeepers, students' understandings of energy flow in food chains/food webs and of the recycling of matter aligned more closely with scientific understandings. This might be related to students' participation in the Earthkeepers program, which has been shown to have effects on participants' understandings (Cincera & Johnson, 2013; Manoli et al., 2014; Činčera, Johnson, & Kovacikova, 2015). The effects of the outdoor program could have been further supported by follow-up activities teachers and students are encouraged to do for reinforcing the learned concepts. However, considering the time span between the program and the following interviews, the effect cannot be clearly attributed to the program.

It could be hypothesized that the program qualities, i.e. framing the taught concepts as meaningful and important to students' lives, outdoor settings, adequate length, connecting with school curricula, instructional clarity of the programs, authenticity of the learning environment or providing experiential-based demonstrations (Athman & Monroe, 2001; Rickinson et al., 2004; Kang et al., 2016; Schnittka & Bell, 2011; The Real World Learning, 2015) might support the process of students' conceptual changes. Still, considering students' struggles with alternative frameworks over five years, it seems to be highly important to emphasize the idea that it is not a single program but a cumulative sequence of outdoor programs, school learning experience, and types of informal interventions that are likely important for helping students develop appropriate understandings of ecological concepts.

The I-A-A model applied in the program seems not to be consistent with instructional strategies for facilitating conceptual change recommended by some of the authors (Athman & Monroe, 2001; Butler et al., 2015; Duit & Treagust, 2003; Kang et al., 2016). However, contextual factors should be taken into consideration. First, the learning process cannot be expected to be facilitated by an outdoor program alone but should be always seen as a combination of students' school and outdoor work. In addition, the process of identification of students' misconceptions and consequent modification of the learning activities is hardly manageable in the limited time of an outdoor program, led by leaders not acknowledgeable of students' needs. As Kirschner, Sweller, and Clark (2006) argue, a direct-instruction approach may be actually more effective for teaching specific knowledge than a less-guiding constructivist approach. The problems they perceive, e.g. the high working memory load of un-guided learning, may be further underscored by the novelty effect an unfamiliar, outdoor environment may have on students (Boeve-de Pauw, Van Hoof, & Van Petegem, 2018; Orion & Hofstein, 1994; Rickinson et al., 2004).

In light of this, it can be argued that the applied strategy is a reasonable choice in the given condition. However, its effectiveness could be further increased by a more elaborated interconnection between the outdoor activities with the previous and follow-up work in schools (Orion & Hofstein, 1994; Rickinson et al., 2004). While all of the earth education programs recommend both pre- and follow-up school activities, a more specific approach, encouraging teachers discussing students' original preconceptions and challenging the emerged misconceptions after the program, could bring a stronger effect.

This raises an important question of how to link an outdoor program with formal education to maximize the potential of both. This provides an opportunity for further investigation.

5. Conclusion

Students' growth in understandings could be described as a non-linear process of enriching, differentiating, abandoning, and re-vitalizing students' original misconceptions, based on a mixture of their direct experience and learned knowledge. Among the most often noticed misconceptions were the idea of the dualism of living and a non-living world and the existence of more primary sources of energy for plants.

The process of students' progression seemed to be partially moderated by their participation in the earth education programs, especially by the first of the programs (Earthkeepers).

The study highlights the importance of repeated exposure of students to educational programs aimed at developing their conceptual understanding and the role of students' direct experience in this process. While some of the programs' features likely supported students' learning, for more effective conceptual development it seems to be important to link the programs more closely with in-class work both before and after students' participation in an outdoor program. These activities should be focused on initial assessing of existing students' alternative framework and misconceptions to help them students in the process of their challenging, altering, or replacing by scientifically more sound concepts learned outdoors.

Although the study demonstrates the potential of outdoor environmental education programs for developing students' scientific literacy, it also calls for an more purposeful way of linking learning outdoors with the classroom.

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