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RESEARCH ARTICLE

First-Year Pre-service Primary School Teachers' Conceptual Structure of Ecosystem Ecology Concepts

Christina Glettler*
Kirchliche Pädagogische Hochschule Graz, Austria
christiana.glettler@kphgraz.at

Gregor Torkar
University of Ljubljana, Slovenia

Science education research has been increasingly concerned with students' and teachers' conceptions of central scientific concepts over the past decades. However, science teaching today should not only convey knowledge but also values and science practices in order to empower students to become responsible citizens in a world that is facing ecological as well as social problems. Thus, a profound understanding of ecology and systems thinking skills are seen as paramount. This paper explores first-year pre-service primary school teachers' conceptual understanding of ecology through the use of a word association test. Students were given four stimulus words and asked to provide five response words to each stimulus. Furthermore, they were asked to formulate a sentence related to biology, using each stimulus word. Response words were categorised and the frequency of the words was calculated. The findings show very limited understanding of the ecological concepts and their interrelatedness. Furthermore, the students showed numerous misconceptions regarding energy flow and food chain relationships. Thus our findings support other authors' propositions that students often struggle with understanding ecology concepts. The findings further imply that the instruction students receive at school is not successful in replacing existing misconceptions with accurate science concepts.

Keywords: ecology, misconception, food chain, concepts, pre-service primary school teachers

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Introduction

Research on students' and teachers' conceptions has become one of the most important domains of science education research during the past few decades (Duit & Treagust, 2003). Findings show that students very often possess some pre-instructional knowledge or beliefs about the phenomena and concepts to be taught in science education. Children and adults try to make sense of their experiences which can lead to pre-instructional conceptions and ideas also called 'children's science' and 'folk science' (Gilbert, Osborne & Fensham, 1982; Inagaki & Hatano, 2002; Keil, 2010). A considerable amount of this intuitive knowledge is not in harmony with science views (Duit & Treagust, 2003), therefore, examining the acquisition of learners' knowledge is important for the success of instructional processes (Palmer & Suggate, 2004).

Student's science knowledge construction is based on pre-instructional knowledge and experiences (Piaget, 1970; Vygotsky, 1980) which has to be restructured in order to allow the acquisition of science concepts. The term conceptual change is used to describe this transformation – to denote learning pathways from students' pre-instructional conceptions to learning the science concepts (Duit, 1999). However, as Duit and Treagust (2003) point out, certain criteria have to be met for conceptional change to be successful – the learners have to be dissatisfied with their existing concept and the new concept has to be plausible, intelligible and fruitful. Furthermore, even if these criteria are met, original concepts are not replaced by the newly learned concept. Students will merely increase the use of the concept that makes better sense to them.

Nowadays, science education should not be only about knowledge construction. Science education should include its nature, its methods, as well as its social, ideological, historical aspects (Jordan & Duncan, 2009). Another important aspect held as indispensable for science teaching are worldviews that have an important consequence for the way in which students perceive and act towards nature and other human beings (Korfiatis et al., 2004). Consequently, there is a growing interest in the representations derived from the science of ecology in recent years and a clear "need to foster students' ecological background knowledge and integrative, systems thinking skills for making principled decisions about complex environmental issues" (Hogan 2002, p. 341). Hokayem and Gotwals (2016) pointed out that it is important that students understand critical environmental issues such as global warming and loss of biodiversity, therefore, the task of ecology education is to teach students the structure and function of the ecosystems as well as their interrelations with humanity (Korfiatis, 2018).

Difficulties in grasping ecological concepts

Several studies report that students often have difficulties understanding ecological concepts (Adeniyi, 1985; Allen, 2017; Eilam, 2012; Hogan, 2000, Hovardas & Korfiatis, 2011; Hokayem & Gotwals, 2016; Leach et al., 1996, Özkan, Tekkaya, & Geban, 2004; Torkar & Krašovec, 2019; Wyner & Blatt, 2019). The reasons for these difficulties are manifold and include ecology's interdisciplinary nature, ecological theories' low level of generality (Gonzales del Solar & Marone, 2001) or the complex systemic nature of ecosystems (Grotzer & Bel Basca 2003; Hmelo-Silver et al. 2007). The origin of many misconceptions about systems in ecology stem from a limited understanding of the basic nature of causality and the limited recognition of the ecological feedback loops (Hogan, 2000). It has been repeatedly reported that students think only about simple interactions between organisms, i.e. in terms of isolated food chains rather than in complex food webs (Jordan et al., 2014). Eilam (2012) reports that students in ninth grade have

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* Corresponding author

difficulties in grasping complex ecological concepts from their compartmentalized knowledge, limited system thinking skills, and common misconceptions and naïve beliefs.

Dauer and colleagues (2014) state that college students still struggle to explain where the matter, making up the plant, comes from. They further state that students generally give little attention to where matter comes from and where it goes. Wyner and Blatt (2019) report that a majority of interviewed teachers and students were unable to connect the food they eat with ecosystem food webs even though some had proficient understanding of food web interactions, but were unable to connect school science understanding with the daily life activities. Although ecosystems are an important primary school topic in many countries, students still struggle in understanding the kind of relationships organisms establish between themselves and abiotic environment (Allen, 2017; Hokayem & Gotwals, 2016; Hovardas & Korfiatis, 2011). Hovardas and Korfiatis (2011) stated that the 'Balance of Nature' metaphor has produced cultural, scientific and learning misconceptions about the structure and function of nature. Authors argue that the faith on that kind of metaphors is reinforced by the fact that ecology is mostly taught in schools as a set of facts, not practicing scientific methods of exploring ecological concepts and processes. However, as the research of Dauer and colleagues (2014) shows, even practical instruction based on experiential learning still does not eradicate all misconceptions. They explain that "these persistent problems are associated with powerful and appealing explanations that plant growth is an action and that water, air, sunlight, and soil are enablers of this action rather than sources of matter and energy that are transformed in living systems" (Dauer et al., 2014, p. 408).

Ecology education in Austrian secondary schools

In Austria, Biology education starts in primary school, integrated in the subject Sachunterricht, which aims at providing a basic understanding of phenomena and concepts of history, geography, science and technology as well as introducing early science skills. Based on this early science education, all students have compulsory Biology education in at least three years of lower secondary school. In upper secondary the amount of Biology lessons depends on the school type. Ecology is usually taught in second grade (general introduction, forest ecology), third grade (soil, decomposers, aquatic ecosystems) and fourth grade (rural ecology, foreign ecosystems, e.g. ocean or desert).

In preparation for this paper, seven approbated Austrian schoolbook series (Burgstaller & Schullerer, 2008, 2009, 2010; Gloning & Hofer, 2013, 2014a, 2014b; Jilka & Kadlec, 2009a, 2009b, 2010; Keil & Ruttner, 2001, 2003, 2004; Möslinger & Schirl, 2011, 2012; Rogl & Bergmann, 2003, 2004, 2005, 2006; Schermaier & Weisl, 2008, 2010; Schermaier, Weisl & Miksche, 2011) were analyzed according to the content they present on ecology. In general, it can be said that in all the books photosynthesis is a covered, explaining that the energy for this process comes from the sun. However, when food chains or energy pyramids are presented, sunlight is not mentioned explicitly in most of the textbooks. Especially the pictures of the food chains mostly leave out the sun. Only in half of the textbooks the sun is pictured in food chains. Another interesting aspect is that seven of the eight textbooks use the word decomposer (Destruent in German) and in one the German word Reduzent is used, which would translate as "reducer". Some of the textbooks change the terminology in the same textbook (e.g., Burgstaller & Schullerer, 2008, 2009, 2010; Gloning & Hofer, 2013, 2014a, 2014b).

The research goal and objectives

As has been shown above, many students lack a full understanding of ecological processes and do not progress from pre-instructional conceptions to science concepts. Yet, little research has been done beyond school age (with the exceptions of Dauer et. al., 2014; Wyner & Blatt, 2019). In order to provide quality science education however, it is vital that teachers themselves have a thorough understanding of science concepts. If, as the cited studies suggest, many students enter universities lacking fundamental ecological and other science concepts, it is thus necessary to change instruction during teacher education in order to ensure teachers' proficiency to relay science concepts to children. Accordingly, the goal of the present research was to investigate Austrian first year pre-service primary school teachers' conceptual structure and interconnectedness for given key (stimulus) words: 'sunlight', 'food chain', 'fungus', and 'decomposer'. These words were considered relevant for the university Biology course and, according to the literature, diagnostic for evaluating students' understanding of ecosystem ecology.

The main research objectives underlying this study were:

- to explore students' understanding of concepts related to ecosystem ecology,
- to study interconnectedness between stimulus and response words and to identify their misconceptions about ecological concepts.

Methodology

Sample and sampling

Altogether 74 students from an Austrian teacher training college, all in their first year, took part in the study; 90% of them had previously attended an Austrian secondary school gaining their school leaving exams there. 60 % of those had attended schools providing general education. The others came from vocational schools such as schools for early childhood education, commercial high schools or forestry schools. The other 10 % had done job training and later sat a university entry exam. Interestingly, only 47 % of the first-year students started their studies straight after leaving secondary school. The other 53 % had been enrolled at another undergraduate study program before coming to the teacher training college. While the total number of first year students was 90, only 74 were present at the time of data collection.

Data collection

The word association test was used in the present study. The word association method is used to assess students' conceptual structures, i.e. their mental representations of the stimulus words in science education (Hovardas & Korfiatis, 2006). Four stimulus words were used to assess students' representations prior entering a university Biology course. For each stimulus word, students were required to list up to five words, which they consider to be most closely associated with the stimulus word. Each stimulus word was placed on an instrument with five blanks attached. In addition, students were asked to use each stimulus word in a meaningful sentence for biology. The test was conducted during a seminar on teaching science in primary schools and supervised by the researcher (first author).

Data analysis

Response words for each stimulus word were classified inductively, according to empirical data of the present study. Response words with the same meaning were coded together. Low-frequency words with the same meanings as high-frequency words were subsumed under the more frequent (general) ones. Data were coded separately by two researchers. Inter-coder reliability was high (> 90%). The words were categorised using a criterion of semantic relationship (e.g., Torkar & Bajd, 2006; Sato & James, 1999) and the frequency of the words was calculated. The strength of interconnectedness between stimulus and response words was assessed using word frequencies. A count was made for the class as a whole, and cut-off points were set for words mentioned more than 5, 10, 20 and 30 times in response to the stimulus words (see **Table 1**) (Bahar, Johnstone, & Sutcliffe, 1999). Sentences in which students used stimulus words were qualitatively assessed and misconceptions described.

Results

All response words to each stimulus word in the word association test are presented in **Table 1**. In total 360 response words were provided by students in their responses to the stimulus 'food chain', 364 responses for the stimulus 'fungus' and 367 responses for the stimulus 'sunlight'. In contrast, only 130 responses were given for the stimulus word 'decomposer'. **Table 1** shows a 'map' which was drawn using the frequency of response words to each stimulus word (sunlight, food chain, fungus and decomposer). This 'map' shows that students did not report all the stimulus words as linked even remotely to each other. For example, the response word energy is linked to sunlight and not to food chain as it would be expected. Similarly, the response word photosynthesis is only linked to key word sunlight and not to key word food chain. The response word fungus is only weakly linked with food chain and decomposer. Response words for food chain do not relate to energy, but rather describe interspecies interactions and eating habits of organisms in the food chain.

Table 1. The interconnectedness between stimulus and response words using word frequency.

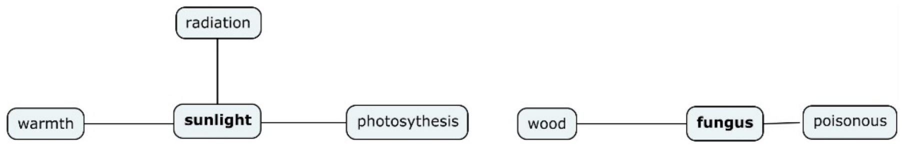
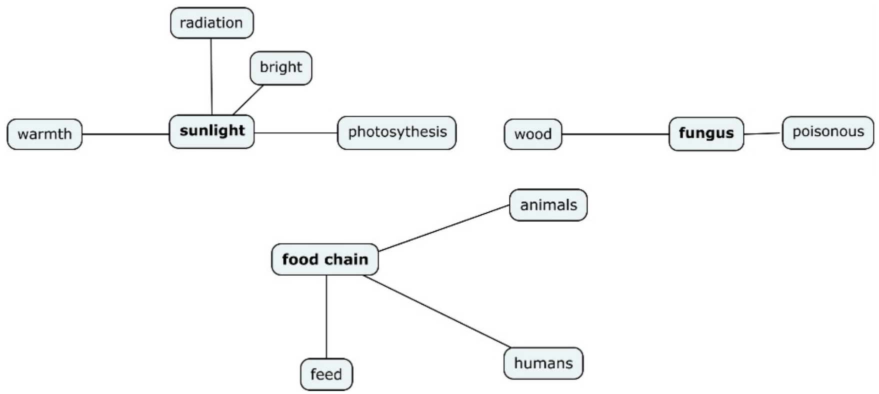
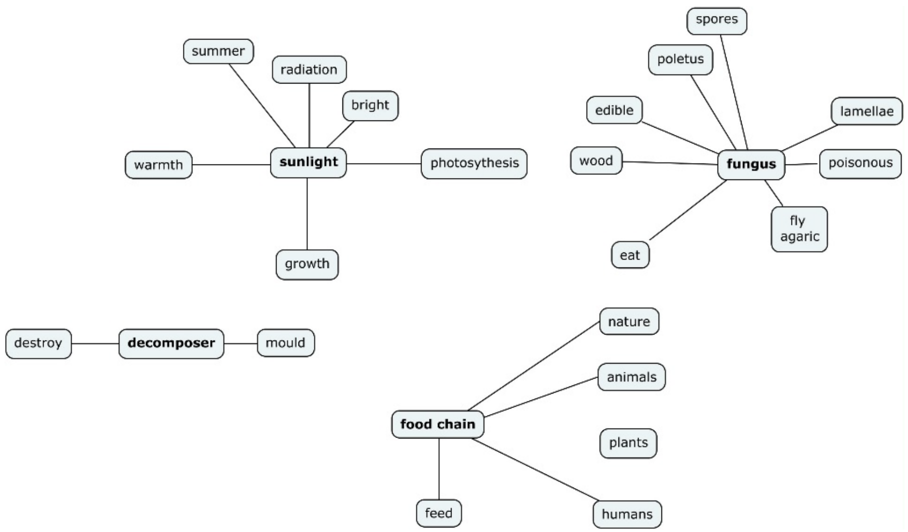
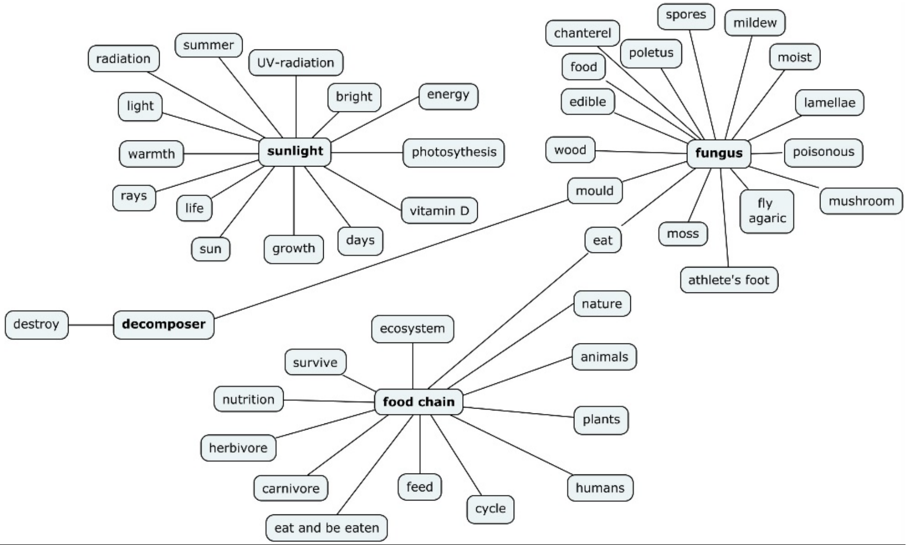
Cut-off point	Map
30 **strong**	
20	
10	

Table 1 continued

5 weak



Students were asked to use each stimulus word in a meaningful sentence. There were 47 (68% of students) correct biological sentences using stimulus word 'sunlight' (e.g., 'Sunlight is needed for photosynthesis', 'Plants need sunlight in order to grow' and 'The human body needs sunlight to produce Vitamin D'). Seven sentences with misconceptions (**Table 2**) were identified and the rest were sentences with no specific biological meaning (e.g., 'The room is filled with sunlight' and 'I like to get tanned in the sunlight').

In the next category, 'food chain' there were 36 (47% of students) biologically correct sentences (e.g., 'Food chains are cyclic in nature'). One sentence did not include the word food chain, two were not related to biology, the rest included misconceptions (**Table 2**), though some might offer ground for debate.

The stimulus word 'fungus' posed less difficulty. However, many of the responses here were unrelated to biology and show an everyday view on fungi. Here, students responded with 47 (62% of students) biologically correct sentences (e.g., 'Fungi are neither plants nor animals', 'Some fungi live in symbiosis with trees' or 'The fly agaric is poisonous') and five misconceptions or rather incomplete notions (**Table 2**).

In the category 'decomposers' students provided a total of 28 sentences and only six (8% of students) of those were biologically correct sentences such as 'Decomposers are connected to producers and consumers' or 'A decomposer decomposes biological matter'. Six sentences were misconceptions (**Table 2**), the rest were not directly related to biology (e.g., 'I have no idea what a decomposer is').

Table 2. Identified misconceptions in the sentences of students.

Stimulus word	Sentences with misconceptions
Sunlight	Plants need sunlight, water and soil to grow.
	Plants make photosynthesis with sunlight and CO2.
	With the help of sunlight it is possible to make energy.
	Through the use of sunlight wood-plants can make photosynthesis.
	In the plant, CO2 is converted to ATP during photosynthesis.
	Without sunlight humans and animals could hardly survive.
	With sunlight one can produce energy.
Food chain	In nature, the food chain determines what humans and animals eat.
	The food chain is a compilation of everything one should take in foodwise.
	In a food chain there is neither beginning nor end, animals eat other animals and are eaten by other animals again.
	Humans are an important part of the food chain.
	Insects are on the bottom of the food chain, because they get eaten by bigger animals.
	Man is on top of the food chain.
	In the food chain of living things, man is on top.
	At the beginning of the food chain are very small animals.
	The food chain describes the process from small animals to big animals and how they eat each other.
	In nature, due to evolution, there is a certain food chain.
	In the food chain plankton is at the end.
	Very often, the food chain is very long, because a lot of food is imported from abroad.
	In the food chain there are different types of enzymes.
	Our food chain must be balanced and closed.
	The food chain holds the number of animals in a natural balance
	The mouse is on top of a cat's food chain.
	Animals, plants and humans are part of the food chain.
	Through the food chain the feed of every animal is regulated.
	There is a food chain between baby and mother
	Because of the food chain, people have the chance to live.
	The food chain is about eating and being eaten.
Fungus	A fungus mostly grows on moist soil in the woods.
	Fungi mostly grow in the woods.
	Fungi most of all need moist soil in the woods.
	A fungus grows beneath the surface.
	A fungus grows especially well on moist soil.
Decomposer	A decomposer e.g. the cuckoo, uses the resources of others.
	A decomposer lives off other organisms.
	A decomposer uses the attributes of other plants.
	Decomposers don't give anything to others but take useful things.
	A decomposer is something that destroys a system.
	A decomposer is bad for the forest.

Discussion

Ecology has evolved from what once was regarded as 'natural history' into a very complex science and that is how it should be presented in school to nurture the environmentally literate citizen (Slingsby & Barker, 2005). A word association test was used to monitor students' representations prior entering a university Biology course. The response of participants to these stimulus words allowed for the extraction of conclusions on their understanding of the ecosystem ecology prior entering the course (Hovardas & Korfiatis, 2006).

Links between stimulus and response words

The students provided many and diverse responses to the stimulus words 'sunlight', 'food chain' and 'fungus'. This indicates that they were familiar with those words and felt confident in filling in the blanks on the data collection instrument. In contrast, they struggled with the stimulus word 'decomposer', which leads to the assumption that many of them did not know the word or at least did not know much about the concept behind the word. In this respect a possible reason could be the use of different terms in some of the reviewed school textbooks (Burgstaller & Schullerer, 2008, 2009, 2010; Gloning & Hofer, 2013, 2014a, 2014b).

However in order to make a definite claim on this issue, students would have needed to give information on the Biology books they had used during secondary school. The same observation can be made from the analysis of correct biological sentences using above mentioned stimulus words where students again provided the lowest total number of sentences and correct biological sentences with the stimulus word 'decomposer'. Similarly, Özkan, Tekkaya and Geban (2004) reported that students did struggle with understanding the role of decomposers in ecosystems.

The findings further indicated that students had difficulties in grasping compartmentalized knowledge of four selected ecological concepts into complex understanding of ecosystem ecology. This would support authors like Grotzer and Bel Basca (2003) or Hmelo-Silver and colleagues (2007) when they state that students often have problems understanding the systemic nature of ecology. The focus of ecosystem ecology is on matter cycles and energy flow in the ecosystems. Organisms are included as producers, consumers or decomposers. In population ecology focus is on species' populations, their distribution and abundance in space and time (Chapin III, Matson & Vitousek, 2011). Students, for example, in their responses linked energy to sunlight but not to the food chain as it would be expected.

Next, the response word photosynthesis is only linked to stimulus word 'sunlight' and not to stimulus word 'food chain'. This implies, that while they have an understanding, that plants need sunlight in order to photosynthesize, they do not make the connection further. They seem to lack an understanding for the fact that the energy, originating from the sun, is passed on through the food chain.

Moving on to the next stimulus word 'fungus', the results show only a weak link with food chain and decomposer. They associate fungi merely with edible or poisonous mushrooms, or on the other hand with mould and moist woods. The ecological importance of fungi is not represented in the students' responses. Similarly, the response words for food chain do not relate to energy, but rather describe interspecies interactions and eating habits of organisms in the food chain. Similarly, Eilam (2012) reports students fail to regard plants as essential elements in the food chain, that they believe size and strength hierarchies determine chain sequence, and they frequently place humans at the top of food chains. Researcher also report students' deficient ability to link micro-level processes to macro-level phenomena, which might be the case for the described missing or weak links between students' conceptual representations including both scientific and alternative conceptions (misconceptions).

Misconceptions

Misconceptions using stimulus word 'sunlight' were related to explanations of the process of photosynthesis. Students were naming 'sunlight' and other things plants need to grow or to photosynthesize. They named incomplete lists of things (e.g., carbon dioxide was not mentioned) to carry out photosynthesis. Some did not perceive light as a form of energy (e.g., 'With sunlight one can produce energy.'). These findings link to the somehow unclear representations of the role of sunlight in ecology in general and especially in food chains, that were found in many of the common Austrian schoolbooks (Jilka & Kadlec, 2009a, 2009b, 2010; Keil & Ruttner, 2003, 2004; Möslinger & Schirl, 2012). As in past research (e.g., Eilam, 2012; Özkan, Tekkaya & Geban, 2004; Wyner & Blatt, 2019), these findings clearly indicate, that students struggle with these concepts.

The students further showed a rather incomplete understanding of the food chain. Students knew that it has something to do with who eats who, their responses to stimulus words often missing plants and never mentioning sunlight. This finding concurs with Jordan et al., (2014), when they state that students don't think about complex food webs but rather describe simple interactions between organisms. This misconception could again be explained by the fact that many illustrations of food chains in Austrian school textbooks (Gloning & Hofer, 2014b; Jilka & Kadlec, 2009a, 2009b, 2010; Keil & Ruttner, 2003, 2004; Möslinger & Schirl, 2012) leave out sunlight and only present feeding relations. Students do not seem to be aware that energy is transferred throughout the trophic levels of the food chain. These findings link to reports by Allen (2017) or Hokayem and Gotwals (2016) or Hovardas and Korfiatis (2011) that students struggle with understanding the relationships between organisms as well as between organisms and their abiotic environment. In some cases, the food chain was explained in the context of the food chain of the product - from farmer to consumer, leaving the concept of ecology altogether.

In the case of the stimulus word 'decomposer' students seem to have confused it with the term 'parasite' as the sentence 'A decomposer e.g. the cuckoo, uses the resources of others' indicate.

Sentences like 'A decomposer is something that destroys a system' indicate that students might just have tried to translate the word, which in German derives from the same Latin origin as the English word 'destruct'. As far as the sentence 'A decomposer lives off other organisms' is concerned, one could even argue, that this is not a misconception. However it still remains apparent, that the student did not understand the function of decomposers in ecosystems. This again concurs with the work of Özkan, Tekkaya and Geban (2004).

The list of thirty-nine identified students' misconceptions about ecosystem ecology is useful for practicing the conceptual change approach (Duit, 1999) with university students to attempt to change their structure of ecosystem ecology concepts. When students are presented with their misconceptions, the aim is to create conceptual conflicts in which misconceptions could be replaced by scientific conceptions and new conceptions could be then integrated with existing conceptions (Uzuntiryaki & Geban, 2005). However, teaching should not be perceived as correcting students' misconceptions but rather engaging them into reasoning processes about their ideas in relation to misconceptions to explain real-world phenomena or solve problems and also potentially make them more aware of their learning approaches (Campbell, Schwarz, & Windschitl, 2016). A formative assessment strategy called the post-box strategy used to elicit, interpret and address students' misconceptions in Biology, provides a very promising learning approach for students to discuss their initial ideas about biological concepts with their peers and, more importantly, it actively engages students in a process of reconsidering their initial ideas through reasoning about why certain ideas are scientifically correct (Chan, 2019).

Conclusion

The contribution of the present research rests on two main points. First, the findings support other authors' propositions that students often struggle with understanding ecology concepts; it shows that first-year pre-service teachers in Austria poorly understand tested ecological concepts (i.e., 'sunlight', 'food chain', 'fungus', and 'decomposer'). This is vital, since these are basic ecological concepts that are required for teaching in primary schools. Thus, undergraduate study programs for teachers should enable students to deepen their knowledge of ecology in order to ensure the quality of science teaching in primary schools. Second, the instruction students receive in primary and secondary schools is not successful in replacing existing misconceptions with accurate scientific views and concepts. Most probably, students just memorized the "right" ideas by rote and after the end of the learning process return back to their initial, erroneous ideas (Bransford, Brown, & Cocking, 2000). Therefore, we agree with Korfiatis (2018) who endorses the "Structure-Behaviour-Function" approach to complex systems, developed by Hmelo-Silver et al. (2007), to introduce ecological concepts to students. This model was successful in facilitating the students' construction of a food web (Demetriou, Korfiatis, & Constantinou, 2009). The results of the study imply that university teachers should not take for granted that their students have a firm understanding of the science concept they will have to later teach themselves. Thus, Palmer & Suggate's (2004) notion still holds true that in order to ensure the success of an instructional process, it is vital to examine the acquisition of learners' knowledge. In this respect it would not only be interesting but also helpful to increase the quality of science education, that university teachers adopt practices to assess their students' pre-conceptions at the beginning of science courses and adapt their courses according to the outcomes.

Research on this issue inevitably has some limitations. First, the research was completed in one Austrian university with a relatively small sample of students. Next, we wished to encompass in this research a reasonably simple and general list of ecological concepts, but it could be the case, though unlikely, that a selection of different ecological concepts would lead us to different conclusions. For further research, it would be important to explore students' understanding of concepts related to ecosystem ecology after finishing university courses.

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