Introducing network analysis into science education: Methodological research examining secondary school students' understanding of 'decomposition'

Dimitrios Schizas • Evagelia Katrana • George Stamou

In the present study we used the technique of word association tests to assess students' cognitive structures during the learning period. In particular, we tried to investigate what students living near a protected area in Greece (Dadia forest) knew about the phenomenon of decomposition. Decomposition was chosen as a stimulus word because it represents a complex issue and was therefore suitable given the primary methodological objectives of this article. Specifically, we tried to develop a complete theoretical scheme for grasping aspects of complexity concerning the learning of biological concepts. Perhaps most importantly, we made an effort to introduce network analysis within the field of science education and evaluate its usefulness in assessing students' knowledge structures. Network analysis was used to manage the data from the word association test and proved to be quite efficient. It became clear that such analysis may help researchers to relate cognitive structures with underlying patterns, including misconceptions. In our case study, such misconceptions stem from students' knowledge gaps, mainly concerning holistic aspects of understanding decomposition.

Keywords: Cognitive structures, decomposition, misconceptions, network analysis, word association test.

Introduction

The process of knowledge construction in learners' minds is one of the most important topics in the science education literature and it is mostly understood within a constructivistic framework (Carey & Smith, 1993; Driver, 1989; Kuhn, 1993). The majority of researchers treat learners as active agents rather than as empty vessels to be inertly filled with scientific knowledge (Fox, 2001). They also tend to share the assumption that learners' prior knowledge influences the learning process (Novak & Gowin, 1984). More specifically, most researchers suggest that a learner's prior knowledge will include experienced knowledge, scientific knowledge, beliefs, ontological convictions, epistemological presuppositions and worldview (Palmer, 1999; Smith & Siegel, 2004; Vosniadou, 1994), all of which, intermingle with the knowledge being taught in a rather complex manner.

Alternative assessment techniques have been developed to provide insight into what students know or understand regarding a specific subject matter (Ruiz-Primo & Shavelson, 1996;

Sutton, 1980). Many of these techniques are grounded in the assumption of concept interrelatedness as an essential property of knowledge (Cardellini, 2010; Ruiz-Primo & Shavelson, 1996). Specifically, based on the premise that knowledge in a scientific domain is organized around a set of important concepts specific to that domain, researchers infer that to be knowledgeable requires a highly integrated conceptual structure to unite these concepts (Shavelson, Ruiz-Primo, & Wiley, 2005). Thus, they attempt to probe students' perceptions of the relationships between concepts. This goal may be accomplished more or less directly. A word association test (WAT), for example, indirectly investigates the student's knowledge structure, providing wide-ranging lists of words that are associated with a key (stimulus) concept in the student's mind (Gussarsky & Gorodetsky, 1988; Nakiboglou, 2008; Stewart, 1979;). On the other hand, concept mapping directly probes students' perceptions of the relationships between concepts in a subject domain, prompting students to create graphs (Kinchin, 2000; Novak, 1990; Okebukola, 1990; Ruiz-Primo & Shavelson, 1996). These graphs represent concepts (via nodes) and relationships (via labelled lines connecting concept pairs) and are supposed to explicitly reflect structural aspects of a student's declarative knowledge.

Given that the search for new methods of assessing what students know and understand is well under way, the main purpose of this article is methodological. The techniques described above assume that a learner's declarative knowledge forms a structural whole that in an idealized form can be represented as an associative network of linked concepts. However, the prevailing mathematical tool used within social studies to measure, represent and analyze structures namely network analysis (Borgatti, Mehra, Brass, & Labianca, 2009), has not been used in the relevant research. Thus, the primary objective of this study is to introduce this type of analysis within the field of science education and evaluate its use in assessing learners' cognitive structures.

To meet the goals of this study we conducted empirical research. Our research aims to exemplify how network analysis might be used with raw data from a WAT for mapping cognitive structures related to the ecological topic of 'decomposition' among secondary-level Greek students. 'Decomposition' was chosen as a research topic for two reasons. First, although the number of studies exploring learners' conceptions of ecological phenomena continually increase (e.g. Demetriou , Korfiatis & Constantinou, 2010; Eilam, 2012; Jordan, Gray, Demeter, Lui, & Hmelo-Silver, 2009; Liarakou, Athanasiadis & Gavrilakis, 2011) little work has been done to thoroughly explore learners' understanding of decomposition (Cetin, 2007; Yorek , Igulu, Sahin & Dogan, 2010), which is actually one of significant concepts of ecology. And second, 'decomposition' is part of a family of concepts that have been reported in several research papers as complicated and difficult for students to grasp (Finley, Stewart, & Yarroch, 1982; Johnstone & Mahmoud, 1980). Apparently, the complexity and difficulty of declarative knowledge would help us to test network analysis and offer a more complete picture of its potential.

The present case-study was therefore designed to examine how network analysis can help to capture what secondary-level Greek students know about 'decomposition'. Having in mind that science education research has consistently identified a considerable lack of understanding of core ecological concepts and processes in all educational settings (e.g. Cardak, 2009; Cetin, 2007; Demetriou, Korfiatis, Constantinou, 2010; Yorek, Igulu, Sahin, & Dogan, 2010), we assume that secondary-level Greek students hold misconceptions about decomposition. Thus our principal research question is further specified to the question of whether and how network analysis can help to identify such misconceptions.

It is worth mentioning that our interpretation of the results of network analysis is informed by our previous work on the nature of ecological science (authors, 2012), in which ecological concepts were epistemologically treated as belonging to structural wholes, namely 'ecological fields'. As a matter of fact, another methodological objective of this study was to develop a full-

fledged theoretical scheme for addressing such complexity. The hope was to clarify different and interrelated aspects of 'decomposition' from an epistemological standpoint that is primarily normative, focusing on what students should know if they are to understand complex biological concepts.

In what follows, we first present a brief sketch of network analysis. Then, we provide a thorough account of our theoretical scheme. Next, we describe the process of data collection and analysis. Subsequently, we present and discuss the results of the study. Finally, we evaluate network analysis as a research method in the field of science education research.

Network Analysis

Network analysis is a method that has been developed within modern sociology for the study of relationships among individuals or other social entities, such as organizations (Butts, 2008). It is applicable to a great variety of sociological issues ranging from the analysis of concepts within mental models (Carley, 1997; Wegner, 1995) to the study of war between nations (Wimmer & Min, 2006) and its impact has been felt in a number of other fields, including anthropology (Boissevain, 1979), human geography (Robinson, 1998), sociolinguistics (Graham, 2000) and ecology (Kapagianni, Boutsis, Argyropoulou, Papatheodorou & Stamou, 2009).

Network analysis aims to measure, represent and analyze structures and uses specialized jargon and notation. Much of this is borrowed from graph theory, the branch of mathematics concerned with patterns of ties (edges) among a set of entities called nodes (Butts, 2008). In the present study, nodes represent concepts, whereas ties represent links among concepts. 1 A link between two concepts exists when these concepts simultaneously appear in the responses of the same student. These responses provide relatively unrestricted access to mental representations of the stimulus term (Bahar & Tongac, 2009) and, as associations, "reflect structural features of how concepts are organised in memory" (Coronges, Stacy & Valente, 2007, p. 2099). Accordingly, in our cognitive research, graphs illustrate associative relationships "in which concepts are represented by nodes and individuals' associations retrieved from memory serve as linkages between nodes" (Coronges, Stacy & Valente, 2007, p. 2099).

Before considering how networks might be analyzed, we should conduct a brief discussion of network data to clarify the above-mentioned ideas. Network data can be represented in a number of ways, depending upon what is most appropriate for the application at hand (Butts, 2008). In our research, we used the most common data representation: a simple square adjacency matrix n X n with n equal to the number of concepts in our data set. The scores in the cells of the matrix record information about the ties between each pair of concepts. If the concepts i and j are present in the semantic memory of one student, then there is a tie between them and a one is entered in the ijth cell. If there is no tie, a zero is entered, whereas higher values in an ijth cell mean that the link between i and j concepts appears more frequently in the research population (see, for example, Table 1).

Researchers analyzing network data often begin by measuring descriptive properties related to structural features of networks (O'Malley & Marsden, 2008; see Table 2). The most common of these properties are cohesion and centrality. Cohesion reflects patterns exhibited by the whole network (Coronges, Stacy & Valente, 2007), indicating the extent of connectedness of a graph. Various measures (metrics) can be used to estimate it, including density and compactness. Density refers to the proportion of pairs of concept nodes that have ties and is equal to the number of ties divided by the number of pairs of concept nodes (Borgatti, forthcoming). Compactness is a measure of the probability that two concepts are directly tied (Hanneman & Riddle, 2005), indicating how direct relationships increase at the expense of indirect ones. Direct relationships reflect paths of length 1 between concepts, whereas indirect relationships reflect paths of a length

greater than 1 that exist between one concept and another distant one. For example a concept i is indirectly related to concept (node) j when there is a third concept h such that i is adjacent to h and h in turn is adjacent to j (O'Malley & Marsden, 2008). In this case, the length of the path (e.g., the number of lines it contains) is 2.

Table 1. Representation of the initial data taken from middle school students into the form of an adjacency matrix. The scores in the cells of the matrix are frequencies. If the concepts i and j are present in the semantic memory of n students, then a n is entered in the ijth cell.

	Microorganisms	Dead matter	Rot Ten	Animals	Bones	Unpleasant smell	Leaves	Plants	Humans	Fruit	Biology	Dead animals
Microorganisms		7	4	2	1	1	1	0	0	0	1	1
Dead matter	7		3	1	0	1	1	0	0	0	1	0
Rotten	4	3		0	0	1	2	0	0	0	0	1
Animals	2	1	0		1	0	0	2	2	1	0	0
Bones	1	0	0	1		0	0	0	0	0	0	0
Unpleasant smell	1	1	1	0	0		0	0	0	0	0	0
Leaves	1	1	2	0	0	0		0	0	0	0	2
Plants	0	0	0	2	0	0	0		2	1	0	0
Humans	0	0	0	2	0	0	0	2		1	0	0
Fruit	0	0	0	1	0	0	0	1	1		0	0
Biology	1	1	0	0	0	0	0	0	0	0		0
Dead animals	1	0	1	0	0	0	2	0	0	0	0	

Centrality can be measured both on the global or network level of analysis and on the local or node level of analysis. As a local property, centrality indicates network features based on the characteristics of each individual node. In the current analysis, centrality reflects the positions of individual concepts within the associative network and offers insights into the prominence of these concepts (for instance, centrality shows how important a concept is in forging indirect relationships among other concepts). Prominence in our context means that certain concepts possess advantageous structural positions, mediating the semantic relationship between other concepts and thereby having an important role in memory processing. Moreover, centrality is one of the most studied concepts in network analysis and numerous metrics have been developed measuring different aspects of how a given network is focalized on certain nodes (Borgatti, 2005). In the present study, we examined three of them: degree, eigenvector and betweenness centrality. Degree centrality stands simply for the number of edges incident upon a given concept and reflects the extent to which each concept activates and is activated by other concepts (Coronges, Stacy, & Valente, 2007). Eigenvector centrality measures the probability that a concept is directly linked to all others (Borgatti & Everett, 2006), while the idea behind this kind of centrality is that "even if a node influences just one other node, …[which] subsequently influences many other nodes (…[which] themselves influence still more others), then the first node in that chain is highly influential" (Borgatti, 2005, p. 61). Thus, concepts with high eigenvector scores are adjacent to concepts that are themselves high scorers. Finally, measuring betweenness centrality helps researchers to evaluate possible information flows within the network. Betweenness centality

assesses the extent to which a concept lies on the shortest path between every other pair of concepts (Hanneman & Riddle, 2005) and estimates the frequency with which a particular concept is activated when paired concepts are retrieved from students' semantic memory.

Table 2. Network properties and metrics

Local network properties and metrics: attribute network features from the viewpoint of each single node (node level of analysis)	
Properties	Metrics
Centrality: is a measure of the structural importance of a given node and assesses the extent to which a node occupies a more influential position than another	**Degree**: is the number of nodes that a given node is directly connected with and accounts for the size of the neighborhood of this node
	Betweeness: assesses how much "in between" a particular node is, based on the frequency with which this node is found in an intermediary position along the shortest paths linking pairs of other nodes. High-betweeness nodes are often called **key-players**.
	Eigenvector: acknowledges that not all connections are equal and applies a centrality definition, in which connections to nodes with high degree centrality contribute more to the score of the node in question than equal number of connections but to nodes with low degree centrality

Global network properties and metrics: reflect patterns exhibited by the whole network (network level of analysis)	
Properties	Metrics
Cohesion: assesses the extent of connectedness of a network	**Density**: is the proportion of ties in a network relative to the total number possible
	Compactness: is a measure of the probability for two nodes to be directly tied
Centrality: assesses the extent to which the overall network structure is dominated by one or few nodes	**Network centralization**: quantifies how 'dispersed' the centralities of the nodes are
Clustering: assesses the possibility for various nodes to be grouped together	**Factions:** are locally dense regions within networks and reflect subsets of concepts that have strong relations with one another

We also estimated global-level centrality, which reveals macro-level structural aspects of the associated concepts and indicates 'network centralization'. Network centralization is defined as the "global measure of the variance in centrality parameters for a network" (Coronges, Stacy & Valente, 2007, p. 2110). High scores for network centralization indicate that linkages are clustered around one concept or set of concepts. These networks are referred to as centralized and may become fragmented if the central concepts are disrupted. In contrast, decentralized networks,

which have low scores for network centralization, have more evenly distributed links and are more resilient (Scott, 2000).

Another important aspect of cognitive networks is the assignment of concepts to subgroups (clustering) and numerous measures can be used to determine the roles of concepts, whether they have a focal position within network interactions, are isolated or are part of clusters. In the present study, we mostly searched for factions and core/peripheral concepts. Factions are locally dense regions of a network that consist of concepts with strong relationships to one another (O'Malley & Marsden, 2008). These factions are not independent and are often interconnected through structurally important concepts called key players. Key players are concepts with high betweenness scores; they help to maintain the cohesion of the entire network because they are maximally connected to all other concepts and thus, removing them would cause many pairs of concepts to become fully disconnected or at least more distantly connected (Borgatti, 2006).

Finally, core concepts are concepts located at the centre of the network and are closest not only to each other but also to all other concepts. In contrast, the concepts located at the outskirts are referred to as peripheral and are relatively close only to the core concepts (Borgatti & Everett, 2000). In general, the core elements of a structure, whether a social representation (Abric, 1993; Marková, 2000) or an entire scientific field (Lakatos, 1974), are those elements that remain stable, whereas the peripheral elements are those elements that undergo transformations. In the context of cognitive structures, this also means that the core concepts are not influenced by situational variation, whereas the peripheral ones vary from student to student (Hovardas & Korfiatis, 2006).

Theoretical Scheme

Before discussing our data collection process and presenting our analysis of the results, we should note that our assessment of student understanding included four dimensions associated with different aspects of 'decomposition'. The first dimension concerns the "intension" (Van der Steen, 1993, p. 14) of 'decomposition'. Specifically, we argue that someone understands 'decomposition' if features that belong to the meaning of the concept called "defining features" (Van der Steen, 1993, p.13) appear in his/her mind. Like the scientific literature (Begon, Townsend, & Harper 2006), Greek textbooks define 'decomposition' as a 'process during which organisms called decomposers transform dead organic matter or wastes of organisms into inorganic matter'. It follows that the understanding of 'decomposition' presupposes the presence of concepts such as 'decomposers', 'dead organic matter', 'wastes' and 'inorganic matter' in students' minds. Note, however, that such a presence would be meaningful within an educational framework if these related words were considered as a structure.

The second dimension concerns the "extension" (Van der Steen, 1993, p. 14) of 'decomposition'. More precisely, we argue that someone understands 'decomposition' if she/he knows the class of things to which this concept applies (Van der Steen, 1993). Note that 'decomposition' is a process, and that as a process it has an abstract empirical reference. However, the constituent parts of its definition are associated with specific empirical entities. For example, 'dead organic matter' refers to dead animals, dead plants and dead parts of these items, such as fallen leaves, whereas inorganic matter refers to chemical elements, such as water, carbon dioxide and minerals. Note also that intensional definitions are as important as extensional ones. For example, in our case students should know that the decomposition of both dead plants and dead animals occurs via the same process.

The third dimension is related to the holistic nature of knowledge. Several philosophers of science argue that scientific concepts interact and mutually define each other (Baltas, 2002, authors, 2012) and consider the meaning of scientific concepts to be context-dependent (Van der Steen, 1993). Analogous ideas exist within the field of science teaching, in which researchers

claim that the concepts used by students are embedded in larger theoretical structures from the beginning (Carey, 1985; Murphy & Medin, 1985; Vosniadou & Ortony, 1989; Vosniadou, 1994). With this in mind, we can see that the concept of 'decomposition' does not exist in isolation but belongs to a network. This network is determined not only by defining features but also by features that do not to belong to the definition. Such "accompanying features" (Van der Steen, 1993, p. 13) are expressed by a variety of scientific concepts. To identify those concepts in this case, we conducted an epistemological reconstruction of the concept of 'decomposition'. Such a process involves three recommended methodological steps.

The first step is to examine the hierarchical organization of the primary ontological levels. The ontology of primary levels (sociological, psychological, biological and physic-chemical) is a long-lasting debate and it is not our intention to enter into that discussion here. Herein, we will simply note that we agree with Emmeche, Koppe & Stjernfelt (1997), who argue that the relationship between ontological levels is inclusive. This indicated the following: a) higher levels are built upon lower levels e.g., the psychological level is built upon the biological and the physic-chemical, and the biological is built upon the physic-chemical; b) higher-level phenomena cannot be reduced to lower-level ones; and c) phenomena on one level can never change the laws of a lower level. In our case, decomposition is acknowledged as a biological concept and the question therefore arises of what physic-chemical concepts or other information originating from physics and chemistry is necessary to our understanding of 'decomposition'. Research has shown the importance of the conservation law (Leach, Driver, Scott & Wood-Robinson, 1996) and the issue of energy (Driver & Millar, 1986), among others.

The second step is to consider the biological hierarchy at play. The core idea here is that the living world is organized into levels embedded within other levels. More precisely, the entities at higher levels of organization are comprised of entities from lower levels, which can be considered the component parts or 'building blocks' of the higher levels (Looijen, 1998). For example, a population as a whole is composed of organisms, organisms are composed of organs, organs are composed of tissues, and so forth. In such a hierarchy, decomposition is found at the ecosystem level, making it important to consider what concepts, principles or laws at other biological levels affect its understanding. Again research has shown that concepts from lower levels, such as respiration, are very important (Eilam, 2002; Leach, Driver, Scott & Wood-Robinson, 1996).

The third and final step is to seek to determine the scientific paradigm (Kuhn, 1962) or the scientific field (Laudan, 1984) to which the concept under study belongs. It is acknowledged that the term 'decomposition' belongs to what is called the ecosystem 'paradigm' or 'field' (Golley, 1993). In fact, 'decomposition' is related to other concepts associated with the ecosystem's structure and functions, such as the 'food chain', the 'recycling of matter' and the 'biological role' of organisms, and several research studies associate the understanding of decomposition with these concepts (Bischoff & Anderson, 2001; Demetriou, Korfiatis & Constantinou, 2010; Grotzer & Bell Basca, 2003; Hogan & Fisherkeller, 1996; Leach, Driver, Scott & Wood-Robinson, 1996; Palmer, 1999; Yorek, Ugulu, Sahin & Dogan, 2010).

All of these scientific concepts involve accompanying features of the concept of 'decomposition' and influence its meaning. They link the constituent concepts of the definition, indicating the relations between them (Waheed & Lucas, 1992). The law of conservation is an example. It links detritus with the material products of decomposition indicating that the decomposed matter has not disappeared. Another example is respiration, a linking concept that indicates the relationship between the concepts 'decomposers' and 'carbon dioxide'. 'Respiration' at the organism level is the causal mechanism through which the release of carbon dioxide occurs. Thus, this concept supplements the declarative knowledge involved into definition with causal

knowledge, which functions as a stabilizing factor within students' semantic networks and is generally recognized as crucial for the development of children's conceptual thinking (Grotzer & Bell Basca, 2003; Keil & Lockhart, 1999; Rowlands, 2001).

The fourth dimension refers to the ideological orientation of the learners. The concept of ideology is broadly defined as any system of ideas regarding philosophic, economic, political, social belief and ideals (Angeles, 1981). The use of the term 'ideology' to refer to a worldview is also common within the sociology of knowledge (Suchting, 1983). Those who use the term in this manner often consider ideology to be a system of ideas that represents the imaginary relationship of individuals to their real conditions of existence and establishes these individuals as social subjects (Baltas, 2002). Although this sort of definition indicates the applicability of the concept of ideology to educational practice in general, the concept of ideology must be defined more strictly in the context of science teaching. Within this research framework, ideology mostly refers to metaphysical-ontological, epistemological, methodological and axiological claims and assumptions (Säther, 2003) that impose on learners a perspective towards scientific objects. In other words, ideology involves implicit presuppositions that structure and frame learners' perceptions and actions (Fourez, 1988), thereby influencing what is called meaningful learning (Ausubel, Novak & Hanesian, 1978). It is worth noting that the use of the concept of ideology in our study is based on the premise that students' cognitive activities are primarily social activities. That is, students' cognitive activities, rather than being strictly individualistic or psychological, are performed within a common patterned framework that reflects a specific historical socio-cultural context (Augoustinos, 1999; Kouzelis, 1991).

In summary, the understanding of the term decomposition is a complicated issue. As is the case with most biological concepts, the understanding of this term requires us to consider various assumptions and concepts, most of which are complex in their own right. These assumptions and concepts are often heterogeneous; assumptions refer implicitly or explicitly to different aspects of scientific practice, such as ontology, methodology and epistemology, while concepts a) are of widely disparate degrees of concreteness and abstractness (Garb, Fisher & Faletti, 1985) and b) are associated with different intradisciplinary or interdisciplinary levels of organization (Hogan & Fisherkeller, 1996; Klein, 1990; Lin & Hu, 2003).

Methodology

Data Collection

Secondary-level Greek students from the city of Soufli were selected as our research population. Soufli is located in northeastern Greece, in the region of Thrace, a few kilometres from Dadia Forest. The Dadia Forest was designated a protected area in 1980 following the continuous and likely irreversible degradation of the raptor habitat. It is now a main ecotourism destination in Greece.

The principal actor in the ecotourist project is WWF Greece (Svoronou & Holden, 2005). In addition to implementing a long-term and ecologically informed managerial plan supported by permanent scientific staff in the area, WWF Greece has also undertaken the ideological role of increasing public environmental awareness and diminishing the negative impact of the local rural society on the forest by protecting it from human interference. To achieve its intended outcomes, WWF Greece has made an appeal to the voice of science as the only legitimate voice to speak about and manage the forest and in this respect, it has mostly used a scientific rhetoric inspired by the ecosystem 'paradigm' and the romantic worldview (Kwa, 2002). As a result, certain ideological images of nature are emphasized over other possible ones: nature is viewed as a place of reverence (Short, 1991) or as a rural idyll (Cloke & Milbourne, 1992) and the Dadia Forest is

represented as an integral and stable ecosystem, whose performance is clearly demarcated from social influences (for more details see Stamou, Lefkaditou, Schizas & Stamou, 2009).

Soufli was selected as a research area because of the important role that we believe ideological parameters of socio-cultural contexts play in science learning. More specifically, we felt that studying the cognitive structures of students living near a protected natural area would facilitate our effort to present how these parameters influence the understanding of ecological concepts.

It should also be noted that the Greek educational system at the secondary level includes three years of middle school (grades 7-9 and ages 12-15) and three years of high school (grades 10-12 and ages 15-18), whereas our research populations involve students from both schools. Third-year middle school (grade 9 and age 14-15) and first-year high school (grade 10 and age 15-16) students were asked to complete a word association task after they had been taught fundamental ecosystem concepts in school class. Middle school students had been taught the issue of decomposition a few months before the word association test and the high school students had taken an analogous course when they were in middle school. Comparing the two groups was expected to help us to reveal the long-term effects of student learning, which was important because long-term rather than provisional aspects of cognitive structures are crucial to how students understand scientific concepts. Moreover, an approximately equal number of males and females participated voluntarily in our research. On the survey, the students were aware by the authors that they were participating in a research project in ecology and they were asked to write down the first five words that came to mind when they thought of 'decomposition'. A sheet of paper on which the key concept of 'decomposition was printed at the top of the page was provided for this purpose. To prevent distraction from the stimulus word (i.e. 'decomposition') and avoid the so called phenomenon of 'chaining effect' (Bahar, Johnstone, & Sutcliffe, 1999; Bahar, & Tongac, 2009) we reprinted ''decomposition' five times down the side of the page leaving space for analogous students' responses. As the respondents were given 1 minute to respond (the time span for similar studies has ranged from 30 seconds to 2 minutes; Bahar, Johnstone, & Sutcliffe, 1999; Bahar & Tongac, 2009; Cardellini 2010; Hovardas & Korfiatis, 2006; Maskill & Cachapuz, 1989; Nakiboglou, 2008), this number of responses was thought to be optimal (Hovardas & Korfiatis, 2006). The authors also administered the word association test, controlled the time and collected the response forms of the sheets.

Data Analysis

The data analysis was performed in three stages. The first stage involved the categorization of the collected raw data according to intensional or extensional criteria. For example, we used the category of micro-organisms to classify a variety of student responses, such as 'decomposers', 'fungi' and 'bacteria'. Our aim, however, was to capture the richness of each subject's association network and therefore, the use of classification was limited. The second stage involved the transformation of the resulting data into an appropriate form for executing network analysis. Network analysis presupposes the existence of network data, and as we have already discussed, we represented the above-mentioned data in the form of adjacency (Response X Response) matrices (see, for example, Table 1). The third and final stage of the data analysis involved importing these adjacency matrices into the UCINET 6 software application (Borgatti, Everett & Freeman, 2002). UCINET 6 is relatively comprehensive and widely used in network data management (Huisman & Van Duijn, 2005; O'Malley & Marsden, 2008). It offers researchers a graphical representation of networks, including their relationships and attributes and allows for the estimation of various computational aspects of analysis (e.g., centrality, cohesion and brokerage).

Results

Figure 1 depicts the conceptual structure of middle school students. The network is composed of 12 concepts, and the different sizes of the nodes represent different amounts of degree centrality. The node 'micro-organisms' is larger because it is connected to the greatest number of nodes, whereas the nodes 'bones' and 'biology' are smaller because they are connected to the fewest nodes. Similarly, the thickness of the lines indicates the intensity of the relationships between the nodes; the thicker the line, the greater the intensity.
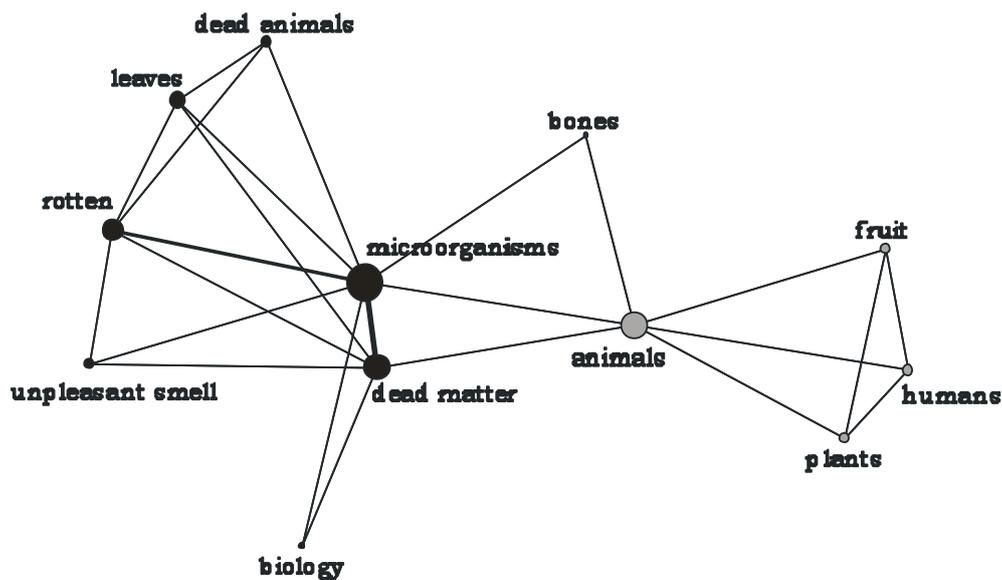
Figure 1. Network of relations between concepts - responses of middle school students to the stimulus of decomposition. The network is split into two factions, which are represented with different color. The members of each faction are more closely connected to each other than to the members of the other faction

The density of the network is 63%, whereas its compactness is 66%. The latter means that the probability of network fragmentation, measured based on the geodesic distance between the nodes, is 34 %. There are 12 nodes in the high school students' conceptual network (Figure 2), which means that the richness of the students' understanding of decomposition based on their responses is the same in both cases. Similar claims can also be made for network density and compactness. They are 54.55% and 69.4%, respectively. Thus far, our network analysis has focused on concerned degree centrality and cohesion. However, our research also focused on centrality metrics, such as betweenness centrality and eigenvector centrality. Tables 3 and 4 present centrality scores for the total network and for each concept. Note that larger values indicate greater centrality.
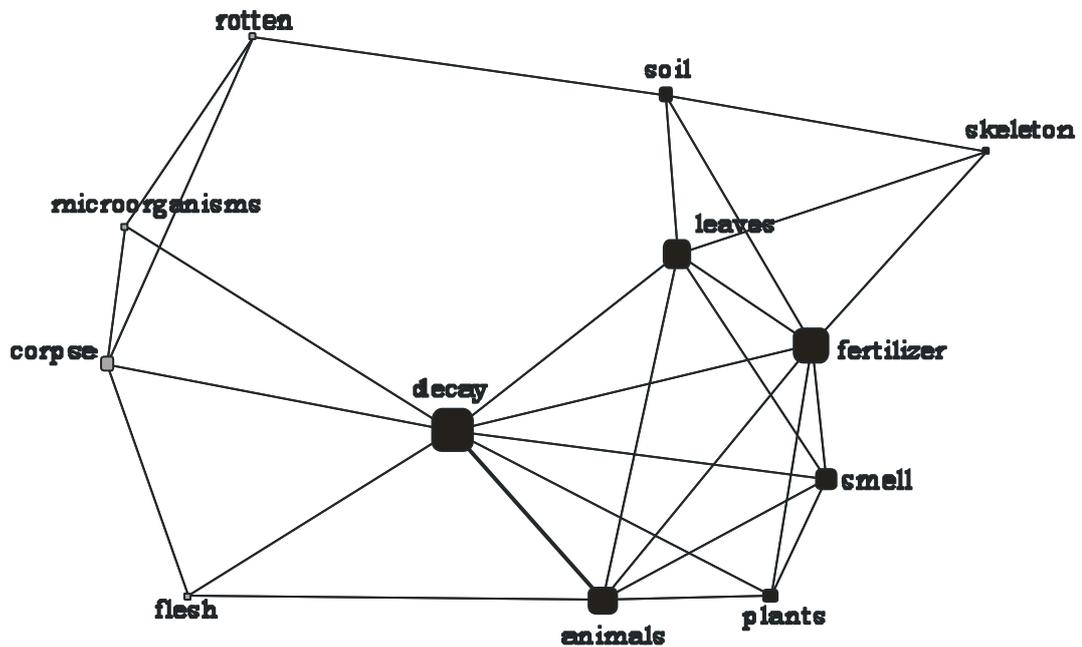
Figure 2. Network of relations between concepts - responses of high school students to the stimulus of decomposition

Table 3. Data of betweenness and eigenvector centrality for the cognitive network of middle school students

Concepts	Betweenness	Eigenvector centrality
Animals	24.500	0.301
Microorganisms	21.167	0.492
Dead matter	9.833	0.418
Rotten	1.167	0.376
Leaves	0.333	0.328
Bones	0.000	0.169
Unpleasant smell	0.000	0.274
Plants	0.000	0.111
Human	0.000	0.111
Fruit	0.000	0.111
Biology	0.000	0.194
Dead animals	0.000	0.255
Descriptive statistics		
Mean	4.750	0.262
Std Dev	8.5433	0.122
Sum	57.000	3.141
Variance	72.975	0.015
Network Centralization	39.17%	50.96%

As observed in Table 3, the betweenness score for the average node in the middle school students' network is relatively high. However, the high standard deviation and variation imply that the betweenness scores do not vary uniformly from one concept to the next. If we also take into account the betweenness of the total network, which is 39.17% of the maximum, then it becomes clear that there are many relationships mediated by the most central concepts. Indeed, estimating concepts' betweenness implies the existence of important differences between the power of the nodes. Nodes, such as 'bones', 'unpleasant smell', 'plants', 'human', 'fruit', 'biology' and 'dead animals' have zero betweenness, whereas other nodes such as 'animals', 'micro-organisms', 'dead matter', 'rotten' and 'leaves', have non-zero scores. However, among these latter nodes, the level of betweeness is quite heterogeneous. The node 'animals' has the highest score, the node 'micro-organisms' has a lower value, and nodes such as 'rotten' and 'leaves' have much lower scores. The high betweenness scores for the first two nodes imply their structural importance; they act as intermediaries connecting other paired concepts and are thereby frequently activated (Coronges, Stacy & Valente, 2007). Occasionally, nodes with high betweenness are characterized as key players because their loss can disrupt the network. In our case, further analysis for key player designation and classification of nodes to different factions showed that one such key player is the concept of animals. Specifically, Figure 1 shows that the entire network can be split into two factions, i.e., subnetworks consisting of concepts that are linked with each other more than they are linked with the concepts from the other faction. One faction contains the concepts 'microorganisms', 'dead matter', 'rotten', 'dead animals', 'leaves' and 'unpleasant smell', whereas the other faction contains the concepts 'animals', 'plants', 'humans' and 'fruits'. Note that the two factions are not independent. The concept of animals bridges them in a cohesive manner and the loss of this concept might fragment the entire network.

Table 4 shows that the betweenness centrality score for the entire high school student network (network centralization) is lower than the corresponding score for middle school students. In fact, within the high school students' network, there are more direct relationships, i.e., relationships between concepts that are only one step away from one another. Nevertheless, as in the middle school students' network, some concepts appear more frequently than others. 'Decay' and 'fertilizer' are such concepts; each one mediates the most relationships in the network, although to a different degree. The influence of these concepts upon other concepts within this network is not equal to the analogous influence of 'animals' and 'microorganisms' within the network of middle school students: it is much smaller. Therefore, in this case, there are probably no concepts that can act as key players. This conclusion is also verified by further analysis: we removed the concepts "decay" and "fertilizer" and all the other nodes remained connected.

Another important metric of centrality is eigenvector centrality. According to the eigenvector centrality scores shown in Table 3, 'micro-organisms' and 'dead matter' hold the most important positions in middle school students' minds. Moreover, Table 3 indicates the significant decrease in the 'animals' eigenvector score in relation to its betweenness score. This decrease implies that the prominence of the 'animals' concept is related more to the amount of information that circulates through it within the network and less on how central the concepts with which it is closely connected are. In fact, the concept of animals is connected more with non-central concepts, and its high betweenness score is a result of its key role.

According to the nodes' eigenvector centrality scores in the high school students' network, 'decay' and 'fertilizer' are the most central concepts. The eigenvector centrality of these concepts is approximately equal to the eigenvector centrality of 'micro-organisms' and 'dead matter', which as we have already observed, play a central role in the middle school students' network. These pairs of concepts, however, do not have the same influence upon other concepts because the centralization of the two networks is significantly different. The centralization of the middle

school students' network measured in eigenvector values is 50.96%, whereas the corresponding value for high school students is 35.83%. This difference implies that the network of middle school students is more centralized, and that its central concepts, 'micro-organisms' and 'dead matter', are more powerful. In fact, within the network of high school students, the differences between the eigenvector centrality values of central and non-central concepts are moderate. Because of these modest differences, some might claim that the distinction between central and non-central concepts within the high school students' network is less clear.

Table 4. Data of betweenness and eigenvector centrality for the cognitive network of high school students

Concepts	Betweenness	Eigenvector centrality
Decay	16.050	0.426
Fertilizer	7.600	0.414
Leaves	5.017	0.367
Soil	4.900	0.198
Corpse	3.183	0.154
Animals	3.150	0.382
Rotten	2.867	0.090
Microorganisms	1.283	0.126
Flesh	0.700	0.181
Smell	0.250	0.354
Plants	0.000	0.296
Skeleton	0.000	0.184
Descriptive statistics		
Mean	3.750	0.264
Std Dev	4.342	0.116
Sum	45.000	3.171
Variation	43.596	0.013
Network Centralization	24.40%	35.83%

Discussion

Our discussion of the results of our research will be divided into three sections. The first section discusses what students know about the starting point of decomposition: the decomposed matter. The second section focuses on how the students perceive the biological transformation of the decomposed organic matter as performed by the decomposers. Finally, the third section discusses the students' cognitive structures in regard to the endpoint of decomposition, which is the production of inorganic matter, including carbon dioxide, water and minerals.

First Thematic Section: The Decomposed Matter

The responses of middle school students include terms such as 'dead matter', 'dead animals', 'leaves' and 'bones'. The existence of these terms in students' minds leads us to draw the following conclusions. First, students may understand 'decomposition' as a process that occurs in dead organic matter. All centrality metrics highlight 'dead matter' as a core concept in the network, at least to some degree. Because of its centrality, 'dead matter' is recalled from students'

semantic memory (Bahar, Johnstone & Sutcliffe, 1999), and if not with any other concept (as the value for betweenness is not very high), then at least with the most central concepts (given that the value for eigenvector centrality is very high). This fact of course is not unimportant. It indicates the strong conceptual influence of this concept on other associated concepts.

Second, concepts such as 'faeces' or even concepts with similar intensional or extensional definitions are completely absent from our results. Thus, middle school students appear to understand decomposition as a process that occurs only in dead organic matter. And third, students probably understand dead organic matter as both animal and vegetable matter. However, decomposed leaves but not decomposing fallen trees are seen as dead vegetable matter.

High school students' responses include terms such as 'corpse', 'flesh', 'leaves', and 'rotten'. The understanding of 'decomposed matter' developed by high school and middle school students has some consistent extensional features; the students understand 'decomposition' as a process occurring in dead organic matter and perceive 'dead organic matter' as potentially either animal or vegetable. Nevertheless, there are also several important differences between the two cognitive networks. For middle school students, as we have already observed, the core concept of 'dead matter' is the only class of things to which 'decomposed matter' is applied. For high school students, in contrast, 'dead matter' is located on the periphery of the network and another concept extensionally related to that of 'decomposed matter' exists at the centre: the concept of 'fertilizer'. What is of crucial importance here is the fact that 'fertilizer' introduces another extensional feature of 'decomposed matter' namely 'dung' into the network. One objection to this interpretation is that the term 'fertilizer' might refer to chemical or inorganic nutrients. However, the high correlation between the concepts 'fertilizer' and 'smell' in students' responses, as well as the fact that students live near a protected area, supports our interpretation. Thus, taking into account the extensional meaning of the concept 'fertilizer', we can draw two conclusions. First, there is strong evidence that high school students perceive decomposition as a process that also occurs in by-products of a living organism's metabolism, such as excrements. Second, the two cognitive networks may differ in terms of ideology. Based on the core concepts of the networks, we might assume that the image, which underlies and organises middle school students' network, is naturalistic, whereas that of the high school students is more anthropocentric.

Second Thematic Section: The Biological Transformation of Decomposed Matter

The centrality metrics for the middle school students' network indicate that the concept of micro-organisms holds an important position. The betweenness centrality scores that we obtained indicate that 'micro-organisms' follow the concept of animals. However, the higher eigenvector centrality value of 'micro-organisms' implies that the range results from local network configurations, which position 'animals' as a key player. Thus, the concept of 'microorganisms' is the most central, which in turn implies that students probably perceive decomposition as a process closely related to the activity of the microorganism decomposers and do not hold common misconceptions concerning the ontological level to which decomposition belongs. Based on such misconceptions, decomposition is usually perceived by students being of approximately the same age as a physical-chemical process and as a process that is caused either spontaneously, gradually and inevitably over time (Smith & Anderson, 1986; Helldén 1998, 1999) or with the assistance of an abiotic factor, such as the wind, the sun, the soil and the heat (Leach, Driver, Scott & Wood-Robinson, 1996; Yorek, Ugulu, Sahin & Dogan 2010).

Like the previous section, an important difference is evident in high school students as compared to middle school students. The concept of 'micro-organisms', which is a core concept for middle school students, is replaced by the concept of 'decay'. Generally, the use of nouns to describe processes obscures the role of agents (Fowler, 1991) and "de-activates" actions,

representing them as though they were things (Van Leeuwen, 1995). It is clear that in our case study, such nominalization might imply the existence of misconceptions in high school students' minds such as of those noted above concerning the perception of 'decomposition' as a physical-chemical process. The existence of such misconceptions in the high school students' cognitive network, however, does not seem to be truly possible because of the simultaneous existence of the concept of 'micro-organisms', even though, the latter is situated in a peripheral position.

The displacement of 'micro-organisms' from the core to the periphery and the emergence of 'decay' as a core condition might also indicate that high school students have a more relational understanding of 'decomposition'. Thus, a plausible hypothesis is that high school students perceive decomposition in terms of processes rather than in terms of entities. In fact, the high centrality of 'fertilizer' seems to support our hypothesis. 'Fertilizer' mostly refers to feeding relations and its emergence as a core concept suggests that high school students consider 'decomposition' to be less closely aligned to its definitional features (their understanding of the term is not limited to the definitional level) and more open to a broader ecological context.

Third Thematic Section: The Products of Decomposition

On this subject, our results are consistent with those presented in many research studies. Students show great difficulty comprehending the transformation of organic matter to inorganic matter (e.g. Hogan & Fisherkeller, 1996; Leach, Konicek, & Shapiro, 1992; Smith & Anderson, 1986). Indeed, in both networks, the absence of the concept 'inorganic matter' or of other concepts denoting extensional features, such as 'carbon dioxide', 'water' and 'inorganic minerals', indicates an explicit deficit in the students' capacity to understand the transformation of matter performed by micro-organism decomposers. One possible explanation for this deficit concerns the inability of students to grasp the complexity of biological hierarchy. Previous research indicates that students are usually unable to understand the mechanism through which this biological transformation occurs. Specifically, they cannot easily comprehend the meaning of respiration (Igelsrud, 1989; Songer & Mintzes, 1994) and, foremost, how this process is connected to material and energetic flows in an ecosystem (Eilam, 2002). In our case study, such difficulties are intensified by the fact that students would not have easily recalled the concept of respiration. That subject is taught a few years earlier in the curriculum, and although Greek textbooks define decomposers as "heterotrophic organisms which take energy from the transformation of dead organic matter to inorganic", they do not clarify how this process occurs. A second possible explanation stems from Reiners' and Eilam's (2001) research and concerns the ontology of levels. These researchers argue that students usually have a mechanical understanding of feeding (i.e., they consider organisms to be automatic machines that open their mouths and put food into their bodies), which impedes their understanding of food's biochemical transformation (in our opinion this obstacle is related to the ontology of levels because it presupposes the identification of food's transformation as a physical-chemical process).

In any case, the conceptual deficit noted in this section complicates the issue of how students perceive the subtopics discussed in previous sections. For example, if we accept that middle school students perceive the process of 'decomposition' to be closely connected to the concept of microorganisms-decomposers, then we must consider how these students perceive this linkage. How do the decomposers effect the decomposition of matter and what is the fate of the dead organic matter? Herein, other misconceptions arise, regarding again the ontology of levels. Does dead organic matter disappear (Leach, Driver, Scott & Wood-Robinson, 1996; Sequeira & Freitas, 1986) or is soil understood as the terminal station of decomposition process (Helldén, 1998, 1999)?

It should be noted that the deficit discussed above, which is obviously important, might be addressed by network associations. Sometimes what is important in a cognitive structure is not the presence or absence of concepts but rather the way these concepts are related to each other (Novac & Gowin, 1984). As Liu (2004, p. 375) states: "The variety of concepts is not as meaningful as the variety of conceptions, because the same set of concepts can be perceived to be related to each other differently depending on different conceptions". Thus, hypothetically, the presence of relationships between existing concepts that establish dead matter as food for plants or assign decomposers a biological role in a food chain might be strong evidence that the students are thinking correctly about the activity of decomposers and the results of decomposition.

A more careful examination of the middle school students' network shows the presence of such relationships between concepts and leads us to believe that when students think of 'decomposition', they recall the idea of feeding relationships. More concretely, diagram 2 shows that the entire network can be divided into two factions, each of which fits specific dimensions of our theoretical scheme. The subnetwork that includes the core concepts of 'microorganisms' and 'dead matter' along with the less central concept of 'rotten' and the peripheral concepts of 'dead animals', 'leaves' and 'unpleasant smell' describes intensional and extensional features of 'decomposition'. In contrast, the subnetwork that includes both the core concept of 'animals' and the peripheral concepts of 'humans', 'plants' and 'fruit', indicates accompanying features of the concept of 'decomposition' related to feeding relationships. Thus, it is possible for students to associate the process of decomposition with feeding relationships occurring in an ecosystem, an association, which as we have already observed, is mediated by the concept of animals.

Furthermore, the idea of feeding relationships is also present within the high school students' network. Its presence is indirectly evidenced by the references to the concept of 'fertilizer', which as we have already observed, places 'decomposition' in a wider ecological context. Note, however, that the idea of feeding relationships is not found in the periphery of the network as it is with high school students. Instead, it is located in the core as one of its constitutive elements. In other words, the relationship between the context (feeding) and the content (the concept of decomposition as indicated by its intensional and extensional definition) is not characterised by externality as it is with middle school students, but it seems to be more a relationship of mutual determination.

We can now return to our question of whether these accompanying features of decomposition compensate for the deficit presented by the conceptual structures of all students, as we have noted in the third section of our analysis. Unfortunately, in this case, we cannot answer with the same certainty with which we addressed previous questions. However, taking into account the findings presented above, we can assume that students may struggle to link the concept of decomposition to the broader context of the ecosystem (for example to link 'decomposition' with the concept of 'recycling of matter'). These difficulties are stated below in the form of working hypotheses and as such can be tested using other stimulus-words or methods, such as questionnaires and interviews.

We observe that the core of the middle school students' cognitive structure, which includes the concepts of 'micro-organisms' and 'dead matter', appears to be incompatible (Chi, Slotta, & de Leeuw, 1994) with the scientific structure of ecosystem theory. Ecosystem ecologists emphasize matter and energy flows rather than biological entities (Schizas & Stamou, 2007) and incorporate the concept of decomposition into the trophic ecosystem structure as a process (Odum, 1982). Students, however, seem to focus more on the entities involved in such a process (micro-organisms, leaves and dead animals) and less on the biochemical decomposition of matter.2

For high school students, the mutual determination between feeding and 'decomposition' implies that context and content are compatible. This compatibility lies on the fact that they share

the same ontological perspective; the perspective of process (Chi, Slotta & de Leeuw, 1994). Nevertheless, there are other incompatibilities at play. Specifically, in mentioning the core concept 'fertilizer', which implies a particular relationship between decomposed matter and the ecosystem's structure, the students reveal that they are envisioning a rural ecosystem. A rural ecosystem, however, is a modified natural ecosystem and as such, it is not consistent with the naturalistic and romantic constitution of ecosystem theory (Schizas & Stamou, 2006; Schizas, 2012). More to the point, a rural ecosystem has to some degree lost its capacity for self-regulation and preserves its stability through external regulatory influences, such as human agency (Bertrand, 1975), whereas system ecologists consider ecosystem as human-untouched nature and describe humans as nothing more than disturbances dislocating nature from its balance (Worster, 1994). Thus, if students link the fate of decomposed material with human intervention in nature, then they may be unable to comprehend the relationship between decomposition and the recycling of matter, which includes the inflow of nutrients to plants via self-regulation.

Evaluation of Network Analysis

In educational research, numerous methods have been developed that are intended to reveal learners' cognitive structures. Many methods, including the WAT and questionnaires, are amenable to quantified data analysis, whereas other methods, such as interviews, are qualitative. Network analysis can be used in both cases. When network analysis is used with the WAT and questionnaires, it can manage data in a more appropriate way than is possible with other statistical research tools, whereas when it is used with interviews, it can provide complementary quantified data analysis. Moreover, network analysis can also be used as a powerful pilot tool for formulating hypotheses and predictions, for organizing structured or semi-structured interviews, etc.

There are many benefits of using network analysis in relevant research. First, network analysis offers a valuable pictorial representation or graph of cognitive structures. These representations are a form of language and convey a great deal of information quickly and directly. In fact, condensation is one of the hall-marks of network analysis. Second, network analysis involves a rich methodological toolkit and offers a multi-dimensional quantifiable analysis of data. Numerous metrics are used to describe and measure structures, making it possible to analyze the relational properties of concepts and the structural complexity of learners' conceptual reservoir. Third, network analysis is a heuristically promising tool for two reasons. The first reason is that it offers fruitful operational definitions of connectedness that make it easy for researchers to reveal underlying theoretical assumptions and misconceptions or formulate testable hypotheses regarding what learners know or understand. The second reason is that network analysis may help researchers generate novel cognitive theories or expand existing ones. Network analysis searches for properties (betweenness, for example) that are common to complex systems. Thus, the transfer of network analysis from the social domain to the domain of science education, along with more research on the applicability of network metrics (e.g., on the implications of each metric for students' understanding or the relationship of each metric to the underlying processes that account for students' understanding), may help researchers to explore unknown aspects of student learning. Moreover, to the best of our knowledge, we were the first to use network analysis in the field of science education and, for this reason, we chose to use network analysis with the WAT. Network analysis is a complex method in itself and WAT compared to other techniques for collecting data facilitates the use of network analysis and enhances the readability of the text. More specifically, the use of the WAT in lieu of other methods for exposing the underlying concepts of learners' cognitive structures (e.g., questionnaires or interviews) simplifies complex methodological stages regarding research design. Such stages involve the transformation of raw data (i.e., the data collected by the above-mentioned techniques) into network data (i.e. the kind of appropriate data

for using network analysis). Furthermore, the WAT is one of the most common methods of investigating students' knowledge structures (Bahar, Johnstone, & Sutcliffe, 1999; Bahar & Tongac, 2009; Cachapuz & Maskill, 1987; Cardellini, 2010; Hovardas & Korfiatis, 2006; Nakiboglu, 2008) and many researchers have stressed its methodological value. For example, Wagner, Valencia & Elejabarrieta (1996) have suggested that WAT allows students to spontaneously express their ideas and consequently, is a more unbiased method of collecting data and extracting results than interviews and closed questionnaires, while Hovardas & Korfiatis (2006) have argued that the WAT, apart from its ease of use, is a heuristically promising technique because it allows for the precise estimation of important aspects of students' conceptual learning.

Conclusion

The main purpose of the present study was to introduce network analysis into the field of science education and evaluate it by assessing students' knowledge about a topic in ecology: decomposition. As is the case with other biological concepts, student learning about decomposition is a complex process. Thus, our aim was to understand how network analysis might help us address this complexity and for that reason, we also proposed a theoretical scheme in this paper. The role of this scheme was to help us interpret the results of our network analysis of raw data from a word association test. In addition to being a canonical theoretical tool for interpreting students' cognitive structures, our theoretical scheme may be proved useful in science education in various ways: it may be used, for example, to guide research design (as it might help researchers to indentify misconceptions and unify isolated misconceptions), or teaching (as it might help teachers to form appropriate classroom questions).

We applied network analysis to science education based on the idea that if the "essence of knowledge is structure" (Anderson 1984, cited in Shavelson, Ruiz-Primo & Wiley, 2005) and the biological concepts are complex concepts (as is inferred from our theoretical scheme), then a method of unraveling the complexity of structures, such as network analysis, wouldn't be but an appropriate method. Indeed, as demonstrated in this article, network analysis provides unique information that can be used to assess what a learner knows about a domain of knowledge. As a matter of fact, our empirical research led us to the conclusion that the concept of decomposition is a difficult topic for students in secondary education. Most difficulties arise from the fact that decomposition similar to other biological concepts requires an understanding that is holistic in its essence. Specifically, third-year middle school students were incapable of understanding aspects of decomposition mostly related to the hierarchical organization of matter. The same, however, was true for first-grade high school students, a finding that also shows the constant and long-lasting character of this learning problem. Further research is probably needed to identify the causes of this problem, although the present study compelled us to hypothesize that the most important trigger is the discontinuities in the Greek curriculum. Concepts related to the understanding of decomposition e.g., respiration, are taught in earlier classes and students are unable to unify them when necessary.

Notes
1. Ostensibly, network analysis shares common features with another research method used in the field of science education, namely concept mapping. However, we have to bear in mind that network analysis is foremost a mathematical tool, a kind of statistical analysis. This means that the methods of network analysis and concept mapping are neither comparable nor competitive.

Besides, network analysis could also be applied on data collected by the use of a concept mapping technique.

2.Two observations might support our claim, although they require further investigation regarding their validity. The first one is quantitative: the term 'rotten' has a very low betweenness value, which probably implies that the associated viewpoint of process is not diffused within the network. This conclusion can be tested as follows: if students perceive an unpleasant smell more as a result of the presence of microorganisms and less as a result of decomposition of organic matter, then it is probably true. The second observation is qualitative. The term 'rotten' specifies the relationship between micro-organisms and dead matter at the level of process, but it seems to do so in a more sensory and less rational way ('rotten' refers more to a visual image and less to the scientific concept of biochemical decomposition of matter), or even in a way that is more static and less dynamic ('rotten' as a visual image describes more a state of matter rather than a developing process).

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Authors

Dimitrios Schizas is an adjunct lecturer in the Department of Ecology at the Aristotle University of Thessaloniki (Greece), where he teaches courses on biology education. His research interests concern historical, philosophical and didactic aspects of biology. **Correspondence:** Department of Ecology, School of Biology, Aristotle University of Thessaloniki, 54124, Thessaloniki, Greece. E-mail: dimschizas@hotmail.com

Evagelia Katrana is a PhD candidate in the Department of ecology at the Aristotle University of Thessaloniki (Greece). Her research focuses on social aspects of ecology. Author's Institution: Environmental Education- Ecotours Officer, Axios-Loudias-Aliakmonas Management Authority, Greece, E-mail address: ekatrana@axiosdelta.gr

George Stamou is a professor in the Department of ecology at the Aristotle University of Thessaloniki, where he teaches courses on ecology. His research interests concern scientific, epistemological, social and political aspects of ecology. Author's Institution: Department of Ecology, School of Biology, Aristotle University of Thessaloniki, 54124,Thessaloniki, Greece. E-mail address: gpstamou@bio.auth.gr