An Exploratory Study of Elementary Preservice Teachers' Understanding of Ecology Using Concept Maps

Kevin M. Zak and Bruce H. Munson

ABSTRACT: Classroom teachers serve a critical role in developing environmentally literate citizens. In this study, the authors assessed K–8 preservice teachers' understanding of basic ecological concepts. Participants (N = 56) constructed concept maps describing the inter-relationships among 16 ecological concepts. The authors analyzed the concept maps to determine how participants organized, associated, and described relationships between the concepts. Although there was a lack of consistency in associating pairs of concepts, participants often created 2 clusters of concepts: a food web cluster and an ecosystem cluster. Associated pairs were often used in similar ways to describe the relationship among concepts. Concepts such as biotic factors and abiotic factors were frequently not used. It is important to ensure that preservice teachers have a solid understanding of ecological concepts before they begin teaching.

KEYWORDS: concept maps, ecology, exploratory study, preservice teachers

Environmental education aims to develop an environmentally literate citizenry that has the "knowledge, skills, attitudes, motivations, and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones" (UNESCO-UNEP, 1976). One underlying component in developing environmental literacy is having a clear understanding of ecological concepts (Disinger & Roth, 1992; Hungerford & Volk, 1990; Minnesota Office of Revisor of Statutes, 2005; North American Association for Environmental Education, 2000). Teachers play a critical role in creating a society in which people develop an understanding of ecological concepts. Thus, teachers need to have a sound understanding of the ecological concepts they are trying to teach. Many researchers have found that teachers who possess a solid understanding of major concepts from their content area are more effective teachers (Buethe & Smallwood, 1987; Fulp, 2002; Gayford, 1998; Moseley, Reinke, & Bookout, 2003; Mosothwane, 2002; Summers, Kruger, Childs, & Mant, 2001).

A teachers' understanding of ecological concepts, like any person's conceptual knowledge, may be illustrated through the use of concept mapping. Concept maps show how individuals remember, organize,

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interpret, and understand information in a particular subject area (Brody, 1996; Derbentseva, Safayeni, & Cañas, 2004; Gerchak, Besterfield-Sacre, Shuman, & Wolfe, 2003; McClure, Sonak, & Suen, 1999; Novak & Gowin, 1984; Rice, Ryan, & Samson, 1998; Ruiz-Primo & Shavelson, 1996; Rye & Rubba, 2002; Stice & Alvarez, 1987; Wallace & Mintzes, 1990; Yin, Vanides, Ruiz-Primo, Ayala, & Shavelson, 2005). The use of concept maps to identify cognitive knowledge is derived from cognitive science and constructivist learning theory (Ausubel, Novak, & Hanesian, 1978; Novak & Gowin).

Concept maps are composed of fundamental units identified as propositions. Each proposition consists of two concepts connected by a linking word or words on a labeled line identifying the relationship between the two concepts. The resulting proposition often reads like a simplified sentence, such as "Trees have leaves" (Novak & Gowin, 1984). An individual's concept map—a network of inter-related propositions—can be characterized and analyzed to assess the map structure, content accuracy, and depth of conceptual knowledge held within a subject area (Johnson et al., 2006; McClure et al., 1999; Ruiz-Primo, Schultz, Li, & Shavelson, 2001; Ruiz-Primo & Shavelson, 1996; Yin et al., 2005).

Artiles, Mostert, and Tankersley (1994) concluded that the presence or absence of certain concepts on preservice teachers' concept maps might be closely related to subsequent teacher behaviors in the classroom setting. If teachers do not have a solid understanding of ecological concepts, their limited understanding may affect their ability to effectively teach these concepts (Buethe & Smallwood, 1987; Hungerford & Volk, 1990; Khalid, 2003; Moseley et al., 2003; Mosothwane, 2002). In this exploratory study, we investigated preservice elementary teachers' conceptual understanding of basic ecological concepts using concept mapping.

Method

We derived a matrix of common ecological concepts from several sources (Biodiversity Project, 1998; Environmental Education and Training Partnership Resource Library, 2002; Klemow, 1991; Landers, Naylon, & Drewes, 2002; Minnesota Department of Education, 2005; Munson, 1994; National Academy of Sciences, 2005; North American Association for Environmental Education, 2000). We also compared and aligned these concepts with the Minnesota Academic Standards for Science in Grades 5–7 and with the National Science Education Standards that outline the science standards that teachers are required to teach to their students in those grade levels. The 16 concepts appearing most frequently among these sources were selected for use in this study: ecosystems, populations, energy flow, community, predator–prey, species, extinction, biological diversity, food web, biotic factors, organisms, adaptations, producers, consumers, abiotic factors, and decomposers. The use of 16 concepts provided enough structure to assess understanding in this content area without the task being overwhelming for participants to complete (Kearney & Kaplan, 1997; Leake, Maguitman, & Reichherzer, 2004; McClure et al., 1999; Novak & Gowin, 1984; Yin et al., 2005).

Participants

A convenience sample of preservice elementary teachers from four teacher preparation universities in Minnesota was invited to participate in this research study. Two institutions were small, private liberal arts colleges, and two institutions were medium-sized public universities. One class section of K–8 preservice teachers from each institution was invited to participate in this study. The participants were enrolled as full-time students seeking their K–8 elementary teaching licensure. Participants were in the final semester prior to student teaching. Of the 56 preservice teachers who participated, 22 were from the liberal arts colleges and 34 were from the public universities. Forty-one of the participants were women, and 15 were men.

Procedure

In a classroom setting at each institution, participants were provided with information about concept maps, procedures on how to create concept maps, an example of a well-constructed concept map, and the instructions and materials for creating their own ecological concept map. They were then asked to imagine that they were developing an ecology unit for students in their sixth-grade classroom. They were provided with the list of 16 ecological concepts and asked to think about how those concepts are related to one another and how they might organize those concepts in a concept map.

Individually, participants wrote the 16 ecological concepts on separate mini Post-It Notes. Each concept was placed on an 11- × 17-in. blank piece of paper (Gerchak et al., 2003; Kearney & Kaplan, 1997). Starting with what they thought to be the most general concept, they organized and created a concept map that included all 16 ecological concepts. If participants were unsure of a concept's meaning, they were instructed to omit it from their concept maps. Once participants were satisfied with their arrangement of concepts, they described the relationships and interrelationships between and among concepts by connecting concepts with arrowed lines and linking words (Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996). Participants were given unlimited time to construct their concept maps, although most completed them within 35–45 min.

Data Analysis

The concept maps provide a visual representation of how a sample population of preservice teachers organized, associated, and described the relationships between 16 basic ecological concepts. We analyzed the data compiled from the concept maps *(N* = 56) for three types of information to provide feedback about the sample's shared understanding of these ecological concepts. One form of analysis applied a holistic, visual approach (Kinchin, 2000, 2001; McClure et al., 1999; Williams, 1998). All concept maps were visually compared with one another. Patterns in structure, content, and organization were identified.

Second, every concept map was broken into its individual propositions, a general step used in a variety of analytical approaches to evaluating concept maps (Derbentseva et al., 2004; Gershak et al., 2003; McClure et al., 1999; Quinn, Mintzes, & Laws, 2003–04; Ruiz-Primo & Shavelson, 1996; Safayeni, Derbentseva, & Cañas, 2005; Yin et al., 2005). Each proposition consisted of three distinct parts: (a) the originating concept, (b) the linking word(s), and (c) the linked concept (see Figure 1). The *originating concept* referred to the primary concept that was connected to a linked concept by an arrowed line. The *linking word(s)* was the descriptive word(s) on an arrowed line that expressed the proposed relationship between the originating concept and the linked concept. The *linked concept* referred to the secondary concept that was connected to the originating concept. For example, the

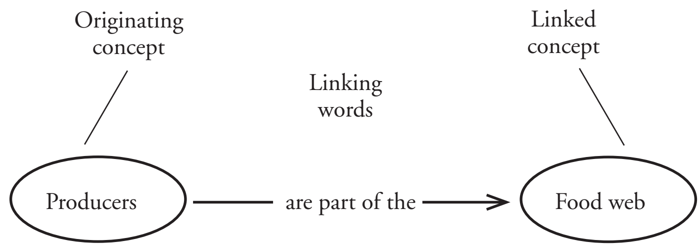

FIGURE 1. Proposed structure of a concept map.

originating concept “producers” was connected to the *linked concept* “food web” by the *linking words* “are part of the,” forming the proposition “Producers are part of the food web.”

Each individual proposition generated was organized in a spreadsheet. These propositions were categorized and sorted by both originating concept and linked concept. This provided an inventory of all the concepts that were connected with each originating concept and linked concept. We used this inventory to determine the total number of links made to and from each concept, the average number of links connected to a concept, and the percentage of participants making associations between any two concepts. We also counted concepts that were not linked at all in the mapping exercise.

Third, we identified patterns and frequencies of participants’ use of propositions. Individual propositions were clustered in groups in which the linking word(s) appeared to identify similar meaning in the relationship among the originating and linked concept. For example, consider the following propositions:

- Community includes populations.
- Community contains populations.
- Community has populations.
- Populations make up a community.
- Populations are found in a community.

The linking words “includes,” “contains,” and “has” were grouped with the reversed propositions that used the linking words “make up a” and “are found in” and identified as having a similar meaning. The similar linking words expressed in these five propositions were categorized under one generalized proposition: “Community contains populations.” The frequencies of generalized propositions were calculated to identify participants’ use of common ecological concepts. The frequencies of generalized propositions were also compared with the percentage of participants making associations between concept pairs.

Results

Concept Map Structure, Organization, and Content

Ninety-three percent of participants created concept maps with “ecosystems” as the most general concept (see Figure 2 for an example). “Ecosystems” was typically positioned at the top of participants’ concept maps, establishing a hierarchical structure. A few participants used “ecosystems” as the central concept from which associated concepts radiated from the center of the map. Regardless of the approach for identifying the primary concept, “ecosystems” typically had three or four concepts linked to it. These concepts identified major subcategories linking clusters of additional concepts. Few concepts linked directly back to the concept of ecosystems.

A visual analysis of the structures of the concept maps showed two main clusters of concepts appeared frequently on many concept maps. The first cluster, the *food web cluster*, included at least four of the following five concepts: food web, energy flow, producers, consumers, and decomposers (see Figure 3). This cluster was linked in some manner on 75% of the concept maps. Some participants did not include one of these five concepts in their cluster. If one of the five was omitted, the concept that was most often left out was decomposers.

The second cluster of concepts that commonly appeared included four concepts: ecosystems, populations, species, and community (see Figure 4). This cluster of concepts, the *ecosystem cluster*, appeared in varying arrangements on 68% of participants’ maps.

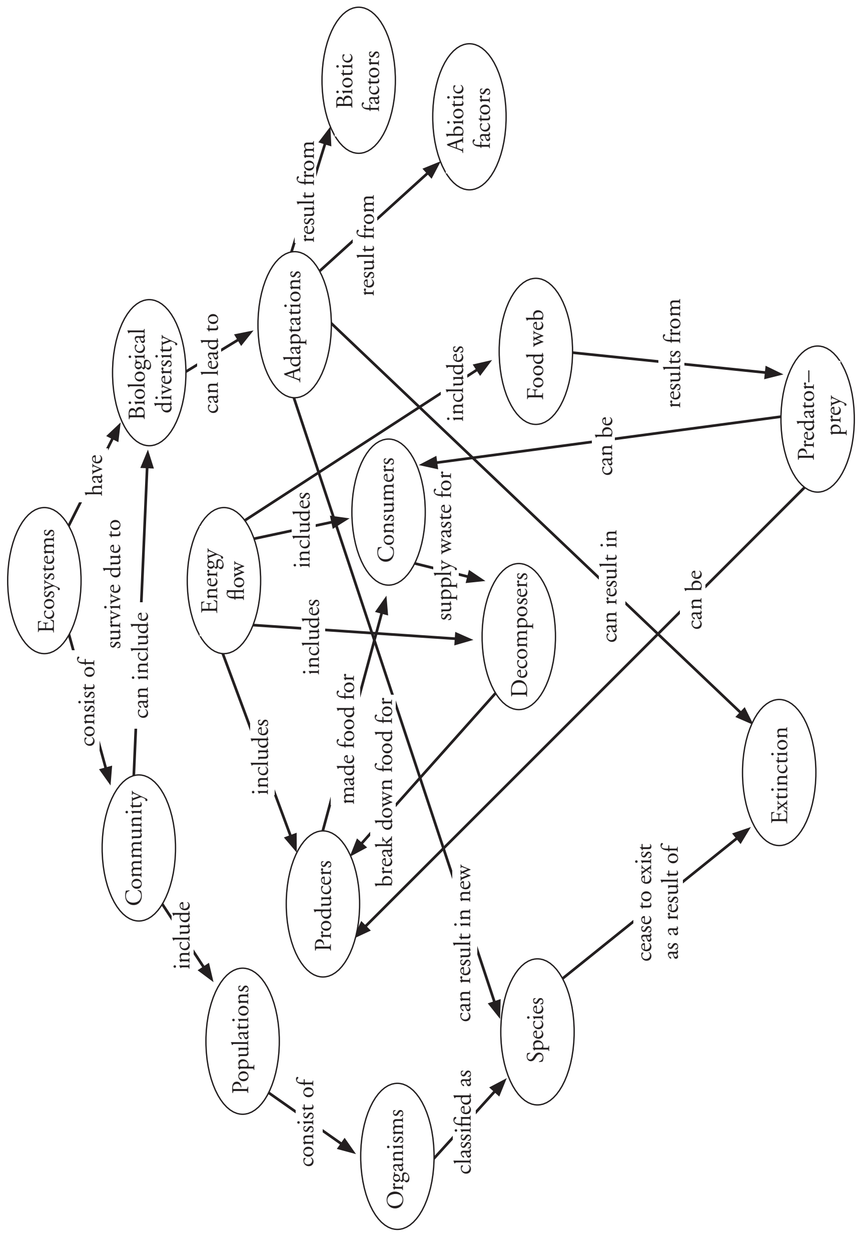

FIGURE 2. Participant concept map with *ecosystems* as the most general concept.

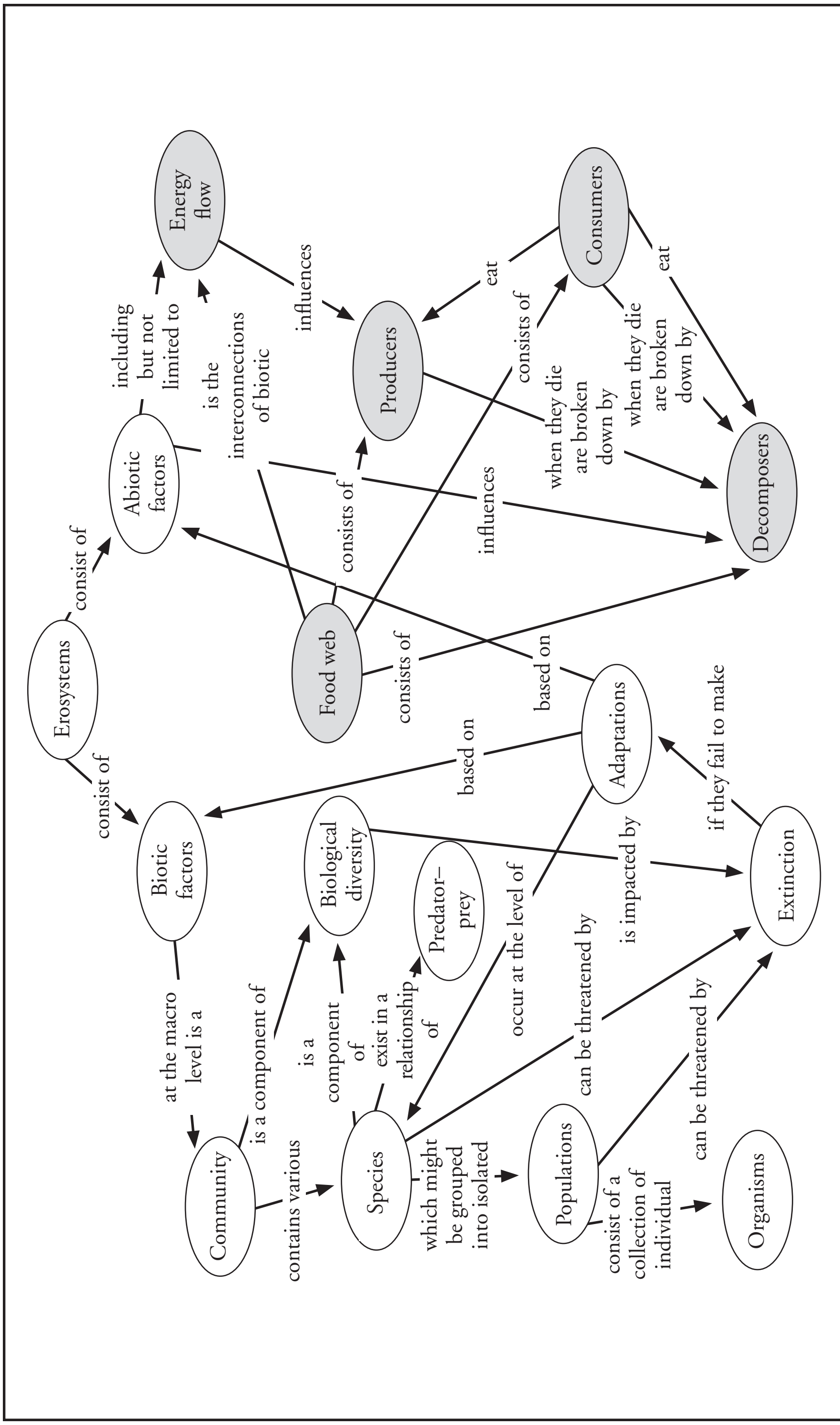

FIGURE 3. **Participant concept map of the *food web* concept cluster.**

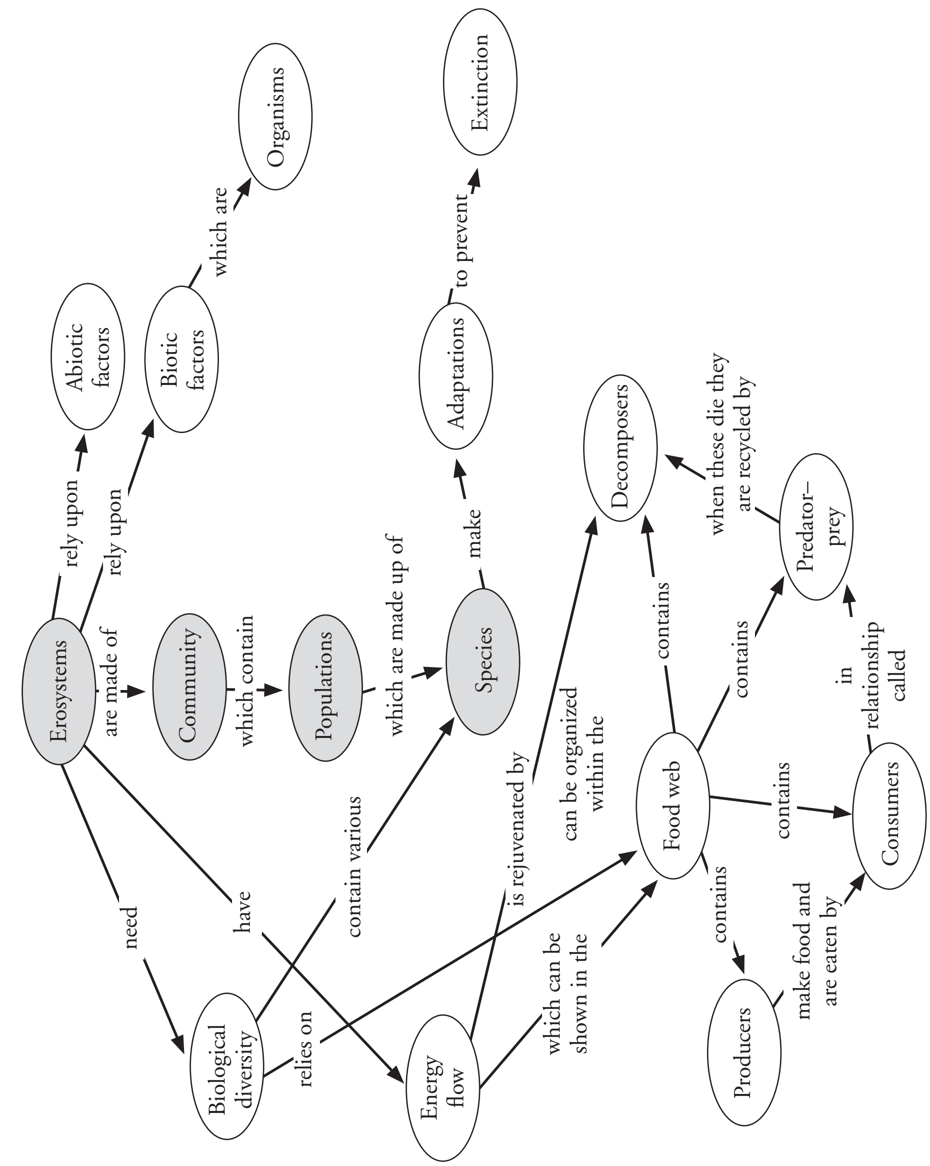

FIGURE 4. Participant concept map of the *ecosystem* concept cluster.

The overall review of maps also showed that several concepts were not used by participants when constructing their concept maps. The percentages of participants who omitted these concepts are listed in Table 1. The concepts “abiotic factors,” “biotic factors,” “energy flow,” and “biological diversity” had the highest frequencies of omission from the concept maps.

Associations Among Ecological Concepts

The concept maps showed that the use of ecological concepts varied. As already noted, some concepts were not used by a number of participants. Other concepts were extensively linked in the concept maps (see Table 2). Participants made the most links using the concepts “food web” and “species.” They made relatively few links using the concepts “abiotic factors” and “biotic factors.” The approach to using each concept also varied with respect to its use as an originating or a linked concept.

TABLE 1. Omitted Concepts, by Percentage of Participants

Omitted concept	%
Abiotic factors	48
Biotic factors	48
Energy flow	13
Biological diversity	11
Decomposers	4
Community	2
Consumers	2
Food web	2

TABLE 2. Number of Links per Ecological Concept

Ecological concept	Originating from concept	Linked to concept	Total links	Average links per concept map
Food web	105	105	210	3.75
Species	125	72	197	3.52
Populations	114	81	195	3.48
Organisms	123	69	192	3.43
Predator–prey	90	87	177	3.16
Consumers	86	90	176	3.14
Producers	78	96	174	3.11
Community	98	71	169	3.02
Ecosystems	151	11	162	2.89
Adaptations	73	79	152	2.71
Biological diversity	77	73	150	2.68
Extinction	58	90	148	2.64
Energy flow	66	77	143	2.55
Decomposers	62	73	135	2.41
Biotic factors	37	36	73	1.30
Abiotic factors	32	34	66	1.18

When all of the propositions created by participants were examined, it became clear that some pairs of concepts were associated more frequently than others. The percentages of all associations that were made between two concepts are shown in Table 3. Sixty-six percent of the concept maps included associations between the concept pairs “community” and “populations” and “food web” and “predator–prey.” Conversely, the analysis showed that participants made no associations between many pairs of ecological concepts. For example, no associations were made for the concept pairs “ecosystems” and “extinction” or the pairs “abiotic factors” and “species.”

Participants’ Ecological Propositions

Participants created many propositions that, although phrased differently, appeared to convey the same meaning. We calculated the frequencies of generalized propositions to illustrate the participants’ understanding of the relationships among basic ecological concepts (see Table 4). Generalized propositions represented less than half of all the relationships identified by participants but still demonstrated patterns of understanding. For example, the generalized propositions “Community includes populations” and “Food web contains producers” appeared on 41% and 38% of the concept maps, respectively.

However, many of the participants who identified a relationship between two concepts also identified the same generalized proposition involving those two concepts (see Table 5). For example, 21 participants identified a relationship between “species” and “adaptations.” Of the 21 participants’ propositions created using these two concepts, 19 (90%) described a relationship that can be represented by generalized proposition “Species make adaptations.” In contrast, 23 participants connected the concepts “adaptations” and “extinction,” with only 10 of them (43%) describing the relationship between them using the generalized proposition “Adaptations prevent extinction.”

Discussion

We conducted this exploratory study to research how future K–8 elementary teachers organize, associate, and describe the relationships among 16 basic ecological concepts. The use of concept mapping provided insights into how this sample of preservice teachers identified the relationships among the concepts. Although it is expected that concept maps will vary among individuals, the results lead to some interesting observations and generalizations.

From an organizational perspective, two clusters of concepts emerged as sets of common relationships identified by the participants. The *food web cluster* (“food web”, “producers”, “consumers”, “decomposers”, “energy flow”) was the most common cluster, recorded in 75% of the participants’ maps. These concepts are typically introduced in elementary school (National Academy of Sciences, 2005) and taught again in middle school and high school. It is reassuring to observe that these future teachers frequently linked this set of concepts. Elementary teachers are not typically strongly grounded in the sciences, so it surprising to see that some preservice teachers include decomposers and energy flow in this networked cluster of concepts.

The second cluster of concepts that commonly emerged was the *ecosystem cluster* (“ecosystem”, “community”, “populations”, “species”). Appearing on just over two thirds of preservice teachers’ concept maps, this cluster illustrated that the teachers identified relationships among these concepts. These concepts are not typically introduced until middle school or later in high school (National Academy of Sciences, 2005). That these concepts were typically clustered with one another in this mapping exercise suggests these concepts have been successfully associated with one another by the participants.

In addition to the holistic analysis of concept maps for organizational clusters, we examined the maps to determine how often each concept appeared. This analysis also illustrated strong differences among participants’ use of each of the concepts. Concepts such as “food web,” “species,”

TABLE 3. Percentage of Participants Linking Each Pair of Ecological Concepts

Concept	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Abiotic factors	—														
2. Adaptations	9	—													
3. Biological diversity	16	23	—												
4. Biotic factors	7	13	20	—											
5. Community	4	5	23	5	—										
6. Consumers	2	5	5	2	23	—									
7. Decomposers	2	4	7	4	5	18	—								
8. Ecosystems	23	7	**43**	23	**45**	13	2	—							
9. Energy flow	11	5	2	5	7	27	30	21	—						
10. Extinction	5	**45**	13	7	2	4	7	1	1	—					
11. Food web	2	4	7	**34**	9	**48**	**38**	23	**41**	13	—				
12. Organisms	4	27	16	9	29	**34**	**32**	20	13	4	11	—			
13. Populations	5	23	23	4	**66**	13	9	**34**	7	14	23	**32**	—		
14. Predator–prey	1	20	5	4	11	**38**	13	4	9	**43**	**66**	16	16	—	
15. Producers	2	4	7	2	20	**45**	18	13	**32**	2	**48**	**39**	16	20	—
16. Species	1	**39**	25	2	**34**	18	18	18	2	25	21	**45**	**46**	**30**	21

Note. Percentages in bold type represent concept pairs that were associated by 30% or more of participants (N = 56).

TABLE 4. Percentage of Generalized Propositions Made by Participants

Originating concept	Linking word(s)	Linked concept	%
community	includes	populations	41
food web	contains	producers	38
food web	contains	predator–prey	36
food web	consists of	consumers	36
predator–prey	can lead to	extinction	34
species	make	adaptations	34
ecosystems	have	biological diversity	30
food web	contains	decomposers	30
ecosystems	consist of	populations	30
organisms	are divided into	species	29
organisms	can be	producers	29
populations	contain	species	27
consumers	can be	predator–prey	25
ecosystems	made up of	community	23
adaptations	prevent	extinction	18
food web	shows	energy flow	18
adaptations	cause	extinction	18

TABLE 5. Percentage of Associated Concept Pairs Generating Generalized Propositions

Originating concept	Linking word(s)	Linked concept	No. making generalized proposition	No. making concept pairing	%
species	make	adaptations	19	21	90
ecosystems	consist of	populations	17	19	89
predator–prey	can lead to	extinction	19	23	83
food web	contains	decomposers	17	21	81
food web	contains	producers	21	27	78
food web	consists of	consumers	20	27	74
ecosystems	have	biological diversity	17	23	74
organisms	can be	producers	16	22	73
organisms	are divided into	species	16	25	64
community	includes	populations	23	37	62
consumers	can be	predator–prey	14	23	61
populations	contain	species	15	26	58
food web	contains	predator–prey	20	37	54
ecosystems	made up of	community	13	25	52
adaptations	cause	extinction	10	23	43
adaptations	prevent	extinction	10	23	43
food web	shows	energy flow	10	23	43

“populations,” and “organisms” were most extensively linked in the maps (see Table 1). From a constructivist perspective, this may indicate that the participants had a better understanding of these ecological concepts compared with other concepts (Ausubel et al., 1978; Novak &

Gowin, 1984; Van Zele, Lenearts, & Wieme, 2004; Winitzky, Kauchak, & Kelly, 1994; Yin et al., 2005).

The concept pairings identified through the participants' linking of concepts is also informative. First, a probable lack of understanding of some basic ecological concepts is shown by the number of participants who chose to not use some of the basic ecological concepts in their maps. (The participants were instructed to leave concepts off their constructed concept maps if they were unsure of a concept's meaning). The concepts "abiotic factors" and "biotic factors" were omitted from nearly half of the participants' concept maps (see Table 1). Participants' lack of use of these concepts is also reflected in the lower frequencies of these concepts being linked to other ecological concepts (see Table 2). This indicates that a substantial number of participants had difficulty linking these concepts in meaningful ways with other basic ecological concepts.

Other concept-pair associations demonstrated the participants were more likely to identify relationships among certain concepts. Concept pairs such as "community" and "populations"; "food web" and "predator–prey"; and "food web" and "producers" were most commonly associated by the preservice teachers (see Table 3). From a constructivist perspective, the meaning of each concept is understood partially through its relationship with other concepts (Ausubel et al., 1978; Novak & Gowin, 1984; Safayeni et al., 2005; Vygotsky, 1986; Yin et al., 2005). Concept pairs that were frequently used are probably meaningfully understood by the participants. At the same time, concerns may be raised by the number of concept pairs that were used by a low percentage of participants. For example, only 7% of the participants linked "biological diversity" and "food web." It is impossible to conclude from the maps that participants did not see a relationship between those two concepts, but it is clear they did not frequently identify one.

Associating two concepts with each other may indicate a general understanding of the concepts, but more detail about an individual's understanding is revealed in the linking words used to describe the relationship between two concepts (Ausubel et al., 1978; Novak & Gowin, 1984; Ruiz-Primo & Shavelson, 1996; Yin et al., 2005). The linking words used to describe some relationships between certain concept pairs resulted in patterns of similar usage and meaning that could be categorized as a generalized proposition for that concept pair. For example, 41% of all participants' propositions could be included in the generalized proposition "Community includes populations" (see Table 4). What may be most striking about these results is how few participants used similar linking words to describe the relationship between concept pairs, resulting in relatively few identified generalized propositions. Only six generalized propositions could be identified that represented the thinking of more than one third of the participants. None of these generalized propositions represented the thinking of more than 41% of the participants. This may indicate the participants hold different meanings for the relationships among commonly associated pairs of concepts. It may also signify that these preservice teachers know that two concepts should be associated with one another, but they may be uncertain of the relationship that exists between them.

Some generalized propositions also invite further investigation. The generalized proposition "Predator–prey can lead to extinction" represents how 34% of all participants described the relationship between these two concepts. This generates questions about participants' understanding of the processes of extinction. The generalized proposition "Species make adaptations" (34% of participants) may represent a common misunderstanding of evolutionary processes. Also, the generalized proposition "Adaptations cause extinction" (18% of participants) may indicate some confusion about the processes of adaptation and evolution. Whether these generalizations indicate a lack of understanding or serious misconceptions requires further study.

A look at the generalized propositions while reflecting on concept pair associations leads to another observation. For the most frequently linked concept pairs, participants usually identified similar propositions (see Table 5). In other words, if participants linked concepts, they tended to make the same statement about the relationship between the concepts. There is more similarity among participants in the generation of propositions than there is in the linking of concept pairs.

The generalized propositions shown in Table 5 also encourage reflection about how the different perspectives on the data generate an overall picture of participants' usage of specific ecological concepts. "Energy flow" is a concept critical to understanding the relationships that exist within ecosystems. The use of "energy flow" by participants raises questions about their understanding of this essential concept. Table 5 demonstrates that, of all participants who linked "energy flow" and "food web," less than half described the relationship in a consistent manner. Table 4 shows that only a small number of participants (18%) developed a generalized proposition describing the relationship between "food web" and "energy flow." Table 3 shows that a relatively high percentage (41%) of participants created a connection between those two concepts. However, Table 1 shows that the concept of "energy flow" was omitted from the maps by several participants. Also, when the number of links to and from "energy flow" is reviewed (see Table 2), it is clear that the concept was used less frequently than most other ecological concepts. These findings encourage further investigation into future teachers' understanding of each of these important ecological concepts through the use of concepts maps and other research methods.

Our findings are significant because the 16 concepts we included in this study are essential components of ecology and are found in the national and state science education standards. Teachers are expected to be able to use and teach these concepts. If future teachers do not have a sound understanding of basic ecological concepts, it is likely to have implications for the understanding that their students may develop regarding those concepts and their relationships with other ecological concepts (Buethe & Smallwood, 1987; Khalid, 2003; Moseley et al., 2003; Mosothwane, 2002).

The data analysis methods used in this study allowed patterns of concept use to emerge from participants' concept maps. We did not focus on individuals but instead attempted to provide insight into the collective ecological understanding of preservice teachers. Simple visual comparisons of all maps resulted in identification of groupings of maps with structural similarities. Our results reinforce the value of this type of qualitative, holistic approach to concept map characterization (Kinchin, 2000, 2001; McClure et al., 1999; Williams, 1998; Van Zele et al., 2004). This technique could allow educators to make generalizations about the nature of a group of participants' understanding of a topic while identifying common map structures and clusters of concepts. These structures and clusters can then be investigated in depth through an analysis of the propositions used to describe relationships among the concepts.

Conclusion

In this exploratory study, we used concept mapping to illustrate K–8 preservice teachers' conceptual understanding of basic ecological concepts. The results indicate important similarities and differences in how the participants applied their knowledge of ecology through concept mapping. Concepts related to food webs and ecosystems were mapped in similar ways by the majority of participants, demonstrating that they may have a general understanding that relationships exist among some of the concepts. However, analysis of map components revealed that some important ecological concepts such as abiotic factors and biotic factors were frequently omitted from maps and may not be understood. A general lack of associations among concepts was found in preservice teachers, perhaps indicating either a lack of understanding or misconceptions about basic ecological concepts and their relationships.

Ecology is about relationships among organisms and the environment. Educators need to be prepared to help their students understand the relationships among basic concepts found in ecology. If they understand the relationships between common ecological concepts, educators will be more effective in guiding their students in developing their own understandings of these concepts (Buethe & Smallwood, 1987; Fulp, 2002; Gayford, 1998; Moseley et al., 2003; Mosothwane, 2002; Summers et al., 2001). Considering the influential role that future teachers have in creating an environmentally literate citizenry, it is important to ensure that teachers have a solid understanding of ecological concepts. There is a demonstrated need to know what preservice teachers know and understand before they teach in the classroom (Hug, 2005). In this study, concept mapping was a useful tool for providing insight into how some future K–8 elementary teachers organized, associated, and described the relationships among 16 basic ecological concepts.

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