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Looking Inside a Student's Mind: Can An Analysis of Student Concept Maps Measure Changes in Environmental Literacy?

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Abstract

This study examined hand drawn concept maps from 34 students, ages 17 – 55, enrolled in a community college environmental biology class. Maps were collected three times during the semester-long course, and analyzed using graphical representation and structural analysis to determine the level of complexity at which students organized and learned the content of environmental science. Graphical changes within concept maps showed a significant increase in the number of complex network-style concept maps generated with a Chi-square analysis calculated a $x^2_{.05}(2) = 7.52$, which exceeds the critical value of 5.99. Structural components within concept maps measured linear increases in the number of nodes, links, and link terms or propositions used. Map components increased by 29% and 35% for nodes and links respectively, and by the end of the semester, measured a 70% increase in proposition usage. In conclusion, significant increases in map propositions and graphical complexity support how students develop skills in articulation of knowledge and demonstrate a more literate understanding of environmental science content.

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Rationale

Understanding the synergistic effects of the interactions of biological, chemical, and geologic factors impacting ecological systems requires students to understand complex relationships among many scientific concepts. Environmental science is a complex discipline that pushes students to see connections among multiple disciplines of learning. In today's world, students who choose to study environmental science examine how local, regional, and global events have interconnected and multifaceted components. Environmental science teachers should use assessment tools that can measure how students understand the conceptual complexity and interrelatedness among systems.

Teachers generally use multiple assessment tools such as exams, quizzes, research papers, inquiry projects, and portfolios to gauge the learning and understanding of concepts studied. One rarely used form of paper and pencil assessment is student-generated concept maps (McClure, Sonak, & Suen, 1999). Concept maps have been used extensively as assessment tools by researchers to determine how students develop a relative knowledge base and interrelation understanding of concepts within science content (Iuli & Helleden, 2004; Van Zele, Lenaerts, & Wieme, 2004). Teachers have also used concept maps as assessment tools to gauge student perceptions of science concepts (Kinchin, 2001; McClure, Sonak, & Suen, 1999; Odom & Kelly, 2000).

In this study, concept maps were used as an assessment tool to examine how students enrolled in an introductory environmental biology course developed more complex understandings of scientific content. Students creating hand-drawn concept maps can graphically demonstrate their interpretations of how the concepts studied in environmental science are interrelated on a single page, while an in-depth essay may take many pages for a student to accurately explain how they envision these same cognitive relationships. By using concept maps, a researcher, or teacher, has a rapid assessment tool for measurement of student interpretation of concepts being studied. The goal for this study was to determine how students' understanding of environmental concepts developed over an entire semester of study, and if students developed a complex integrated understanding of the environmental concepts. To observe how student knowledge construction changed over the course of the semester long class, there were several questions this study investigated. First, does a student's knowledge construction of environmental issues become more complex over the course of the semester? How does the composition of student concept maps, the number of nodes, link, and link terms change from the beginning to the end of a course? And lastly, is there an increase in the graphical complexity displayed in the student's concept maps?

Literature Review

Environmental literacy can have several meanings (Stables, 1998). The most widely accepted foundations for environmental literacy were put forth by the National Environmental Education Act of 1990, stating that literacy can be identified by students displaying knowledge and skills in ecological concepts, conceptual awareness about how behavior effects the environment, knowledge in investigation and environmental action skills (United States Environmental Protection Agency, 1996). In the past, measuring successful acquisition of knowledge in environmental studies has been assessed through pre-post test analysis (Morrone, Manacle, & Carr, 2001), self-reporting surveys (Cullen & Money, 1999), or student interviews (Gayford, 2002). Since environmental science consists of the integration of several scientific disciplines, students are expected to study and learn how concepts in geology, biology, chemistry, or ecology are related and interdependent (Roth, 1992). Restricting assessment to standard tests or survey responses presents a limitation to measuring how a student successfully integrates concepts from several domains of science. This also limits a researcher to verbal responses, which attempt to demonstrate knowledge, but may show a partial picture of how a student understands the complex interrelationships among environmental concepts. Researchers utilizing concept maps may gain additional information to determine how students organize complex, and integrated science concepts.

Researchers utilizing concepts maps as research tools have explored student's knowledge construction in several science disciplines. For example, in biology education researchers examined student concepts maps in order to identify how they categorized information and organized integrated science concepts (Odom & Kelley, 2000). Concept maps have also been used to measure how students demonstrate hierarchical relationships in their understanding of what they have learned (Rice, Ryan, & Samson, 1998). To determine where students demonstrate misconceptions, researchers have analyzed student concept maps to gauge how students may represent their misunderstanding of scientific concepts (Iuli, 2004). In this study, the researcher utilized concept maps to determine how students can demonstrate the complexity of the interrelationships among unique scientific concepts as they relate within environmental science.

A wide variety of techniques have been employed in scoring the complexity of concept maps. Novak and Musonda (1991) emphasize a hierarchical approach to examine the levels of knowledge, the number of nodes (single concepts), links between nodes, and cross-links among nodes. Yin, Ruiz-Primo. Ayala, and Shavelson (2005) used a graphical approach, categorizing maps into groups based on overall shape such as linear, circular, hub & spoke, or network. Yin et al. (2005) proposed several categories of maps considered simple in form and therefore representative of a simple understanding of a particular subject (Yin et al., 2005). Simple categories included maps shaped into *linear*, *tree*, *circular*, and *hub & spoke* (see Appendix A). Maps considered complex were shaped in a *network* (see Appendix A) format in which there were more interconnections than nodes within a concept map. Kinchin and Hay (2000) discussed a methodology of interpreting maps using a more qualitative approach for categorizing maps but classifying maps into three categories: spoke, chain, or net. They argue for using both a qualitative and graphical analysis of concept maps for several reasons, suggesting this method is less cumbersome than numerical scoring and provides more structural interpretation of concept maps. However, having only three categories can be too limiting when attempting to catalog maps into groups based on structure, because the compositions of some maps cannot be fully classified simply as a chain or a spoke. Neither method, as described by Yin et al. (2005) and Kinchin and Hay (2000), had full or complete explanations of how each of these categories of concept maps could be classified. Both authors agreed, however, on how simple structured maps correlated with simple or naïve understanding of scientific concepts while complex or network style maps demonstrated more advanced or mature understanding of the interrelationships among multiple scientific concepts (Kinchin & Hay, 2000; Yin et al., 2005). In this study, these techniques were used in initial analysis of the concept maps, however, results proved to be too subjective in determining the precise placement of various concept maps based on their graphical structure. Student concept maps collected within this study, exhibited variance in both graphical and structural composition and demonstrated significant measurable differences in concept map construction.

In a study conducted by McClure, Sonak, and Suen (1999), the researchers utilized six different methods to score 63 maps collected from undergraduate education students. The scoring techniques ranged from a holistic method, to a subjective technique where raters could award a map with a score from 1-10 based on criteria from complexity, to a structural method quantifying each of the components within a map such as links, nodes, cross links etc. Interestingly, the data the team collected showed a balance in inter-rater reliability when examining composite scores. However, individual analysis methods demonstrated greater variance in subjective graphical scoring methods than in the more time-consuming structural analysis of concept maps (McClure et al., 1999). Kinchin's (2000) qualitative approaches to categorizing maps provide a rapid assessment method for analyzing how students develop mature understanding of biology concepts. Kinchin (2000) further argued, “the construction of a concept map is to reveal the perceptions of the map’s author, rather than a reproduction of memorized facts” (p.44). Following the foundations provided by these researchers, this study examines how student concept maps evolved over the period of one semester of study.

Method

Participants

The participants in this study were 34 students enrolled in an introductory environmental biology course offered through a community college in southern Minnesota in conjunction with two local corporations. The course had an environmental science-focused curriculum that integrated several domains of scientific studies, including biology, chemistry, and geology. Students participating in this course were adults enrolled in the college and employed at either local corporation. This course was offered at the worksite and after work hours for employees to further their education. Students ranged from 17 years old to 55 years old, and it was their first science course after enrolling in community college.

Measures

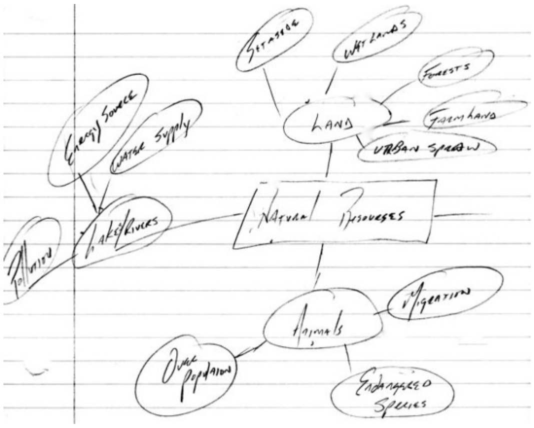
To examine how students organize and display their conceptual framework of environmental science concepts, students were asked to generate hand-drawn concept maps during class time and collected three times during the semester. Students were instructed on how to create concept maps using two approaches. First, students were asked to read a short section of their textbook that described how to create concept maps and showed a simple concept map diagram. The instructor then led a large group class discussion to generate a concept map on the white board using topics and link descriptions forwarded by students during the course of the class discussion. After the large group had completed the concept map on the whiteboard, students were asked to create individual concept maps and encouraged to use examples presented in class to assist them in created their own hand-drawn concept maps. To provide for some randomization of data, students were encouraged to pick any topic for their maps from a list of concepts studied during the course of the semester and written into their syllabus at each point of data collection during the study. Since the students were allowed to randomly pick topics for their individual maps, analysis focused on the structural components of maps from the entire participants in the study group, rather than on changes observed in specific individual’s maps during the semester. The scientific content of any one specific participants’ map could vary during the course of the study; for example an individual could create their first concept map about water pollution, their second map about urban impacts on water, and their final concept map may have been focused on Minnesota lakes and streams.

Concept maps were collected three times during the semester, on the first day of class, with the midterm exam, and with the final exam on the last day of class. This provided a chronology to be used for examining how students progressed in the complexity of their content understanding. These maps were collected, with traditional exams, to be analyzed to observe how content knowledge related to new information learned during the semester.

This study utilized a combination of graphical organization and quantitative data analysis of concept map components. First, maps were scored by tabulating the number of structural components for each map which included counting the number of nodes, links, and link terms (Figure I). Mean scores were then determined for each component of the concept maps, at each collection point during the semester. Ratios of each component were also calculated to see how the composition of student maps changed during the semester. For example, a ratio of the mean number of links to nodes was examined to quantify increases in the number of links used as the number of key concepts increased in student concept maps. Link terms also play a critical role in concept map formation, as these terms describe the relationship between two node concepts (Novak, 1991). Therefore, analysis of the ratio of link terms (propositions) to links generated was also quantified and compared to other components of the concept maps. The percent increase in link term usage was determined over the course of the semester, for the study group.

Scoring of individual maps was statistically analyzed to determine mean values of individual components within maps for each point of collection during the semester. Quantification of the interrelationship of components was also determined through calculation of ratios between the usage of various parts within maps and the percent of total usage of the nodes, link, branches and link terms within class concept map samples. Percent totals for both simple and complex form maps were calculated and differences in percentage were analyzed using chi-square analysis to determine significance. Since concept maps are composed of three major interdependent components chi square analysis provides the most accurate analysis of the goodness of fit between the observed data and the expected theoretical results.

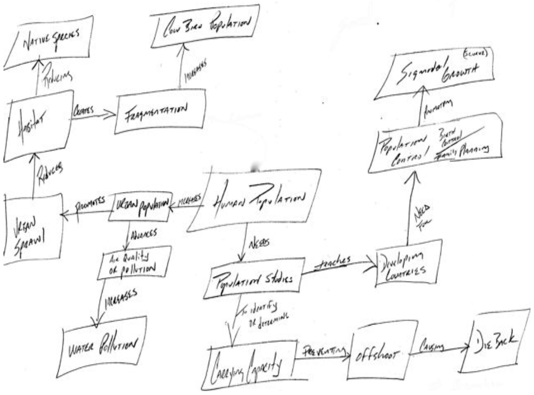
In addition to analysis of propositional complexity, concept maps were analyzed for graphical sophistication (Figure I). Concept maps were grouped, at each collection point, based on the structural categorizations put forth by Kinchin & Hay (2000) and Yin et al. (2005). This included grouping student concept maps into structural categories such as linear, circular, tree, hub & spoke, network or wheel shaped maps based on the qualitative visual comparison of student maps to example templates (see Appendix A). Totals were calculated for each graphical category and statistical analysis to determine percent of total for each category was tabulated (see Table I).



Student 1 concept map from the 1st day
Graphical categorization: Branched Tree

Quantitative analysis:
nodes = 15
links = 15
link terms = 0
Ratio of link terms to links = 0 (propositions)

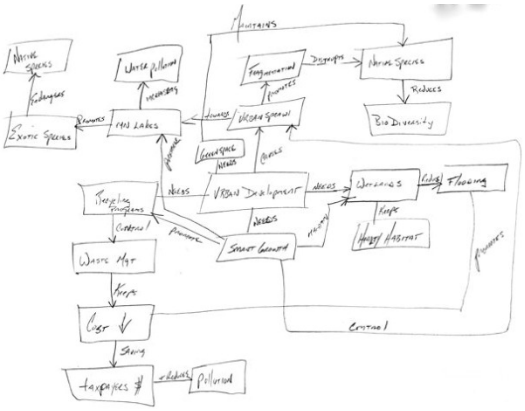
See Appendix B for larger image



Student 1 concept map from midterm
Graphical categorization: Branched Tree

Quantitative analysis:
nodes = 16
links = 15
link terms = 15
Ratio of link terms to links = 1.0 (propositions)

See Appendix B for larger image



Student 1 concept map from final day
Graphical representation: Network

Quantitative analysis:
nodes = 19
links = 23
link terms = 23
Ratio of link terms to links = 1.0 (propositions)

See Appendix B for larger image

Figure I. Exemplars identifying graphical representation and quantitative scoring of one student's concept maps collected three times during the study.

Reliability Measures

In this study the all maps are scored and categorized within a three-month period of the completion of the course. The quantifying of structural components of maps was conducted when all maps form the entire semester had been collected. Each component of the concept maps were gauged for scientific accuracy based on the criteria of science content relevant to the course of study, the textbook used in the course, and any lecture or lab materials available for the students. Data recorded from student concept maps within this study reflects accurate representation of information with reference to environmental science as judged by the researcher and solely responsible for tabulating all structural components of nodes, links and link terms.

Categorization of maps structures were assessed within three months of the completion of the course and collection of all concept maps. Also, the investigator was responsible for all categorization of concept maps based on graphic representation and utilized the same graphic categories for each set of maps collected during the semester. Since the investigator conducted all quantification of data, bias due to inter-rater reliability has been minimized. Also, measurements were conducted within the same time frame to minimize bias in categorization of samples.

Results

An analysis of student maps shows several significant changes over the course of a semester. Since maps were analyzed using several basic methods, the results from each technique will be discussed separately.

Graphical Categorization of Concept Maps

A gradual shift in graphical complexity was observed of the simplest maps, such as the linear and tree formats, to the more complex circular and hub & spoke formats. Percentages of each of the other simple concept map types remained relatively stable through out the semester. Concept maps created in a tree formation had the most stable measurements throughout the semester varying by only 3.5% (see Table I).

Table I

Percentage of student map complexity by type of structure and group for each occasion of sample collection.

Structure	Map Type	1st Day (n=22)	% of total	Midterm (n=34)	% of total	Final (n=29)	% of total
Simple	Linear	2	9.1	3	8.8	0	0.0
	Tree	5	22.7	8	23.5	6	20.7
	Circle	3	13.7	3	8.8	5	17.3
	Hub & Spoke	9	40.9	9	26.5	11	37.9
Complex	Network/Wheel	3	13.6	11	32.4	7	24.1

(Each type of map is hyperlinked to an exemplar to 1st day concept map samples, see Appendix C.)

The study found 9% of students using the simplest linear form of map on the first day, dropping to no students using the linear concept map on their final class. Interestingly, only one student who used the linear concept map format in the early part of the course completed the entire course and received a grade.

Analysis of concept map scoring based on graphical shape and representation, students showed a significant increase in generating complex maps, going from a percentage of the class using complex designs of 13.65% at the start of the course to over twice as many students, 32.35%, using the network style design at midterm. However, only 24.14% of students utilized the complex design on their final exam, a decrease from the previous high value but still demonstrating twice as many students were displaying more complex maps compared to the beginning of the course. The drop from 32.35% to 24.14% is unexpected, but possibly demonstrating that students improve greatly by midterm and then maintain an elevated level of performance for the rest of the course (see Figure II). Statistical analysis of these results using chi-square analysis demonstrates significant differences in the percentage of students generating complex concept maps. Calculating a $x^2_{.05}(2) = 7.52$ x^2 exceeds the critical value of 5.99, and therefore results demonstrate a significant increase in observed complex concept map generation by the end of the semester (see Appendix D for final class network/wheel exemplars).

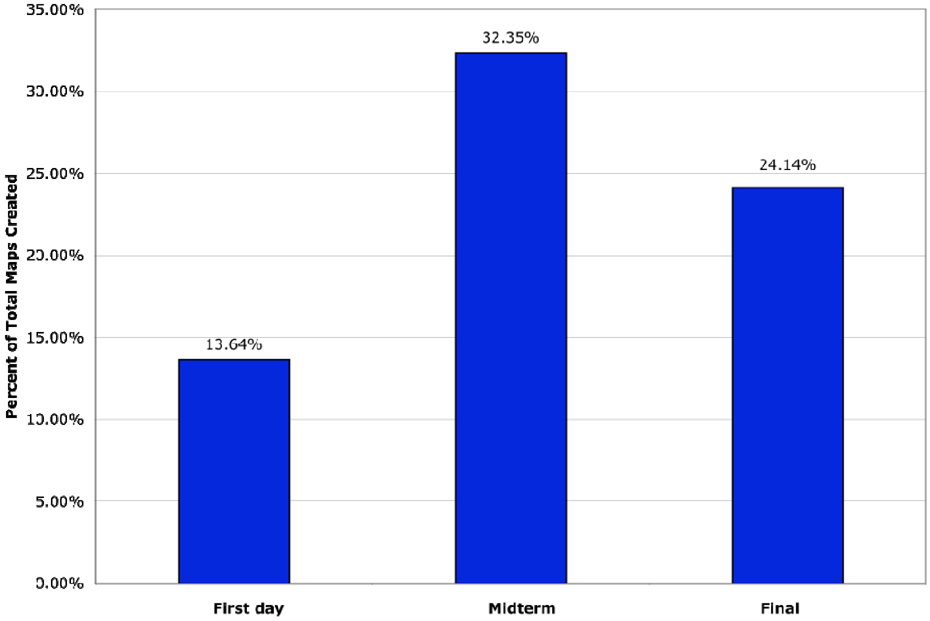


Figure II. Comparison of complex concept map development.

Concept Map Component Usage

In node acquisition and usage there is an almost linear increase observed in student concept maps over the course of the semester. For example, mean increase in node usage increased from 11.64 nodes per map to 16.38 nodes per map, a linear increase of 2.37 nodes per sample. Also, the mean use of links has a similar rate of increase from the beginning of the semester until the final exam, from 12.27 links per map to 18.93 links per map. This translated to a linear rate increase of 3.37 links per sample. Lastly, link term (proposition) usage increased over twice the rate of node acquisition with a rate of 4.88 terms per sample (see Figure III).

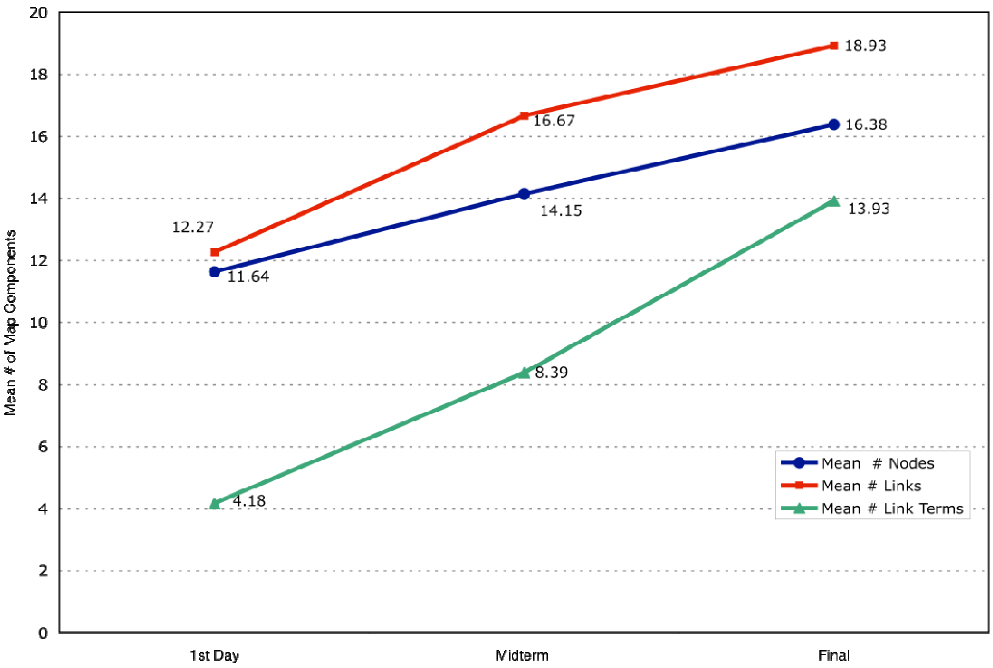


Figure III. Comparison of changes in map component usage.

The most dramatic and significant change in component usage is the mean number of link terms per map changing from 4.18 to 13.93 from first day to final day. Link term usage changes from only one third of links being identified with appropriate terms to an almost 1:1 ratio of number of links to link term usage (see Figure IV). This is a 70% increase in term usage over the course of a semester compared to increases of 29% and 35% for node and links usage during the semester respectively, and is twice the increase in component usage compared to the other two components within maps. A $x^2_{.05}(2) = 21.92$ exceeds the critical value equal to 5.99, and we can therefore reject the null hypothesis that all concept map components have the same percent, which suggests that students demonstrated a significant increase in link term use on their concept maps over the course of the semester.

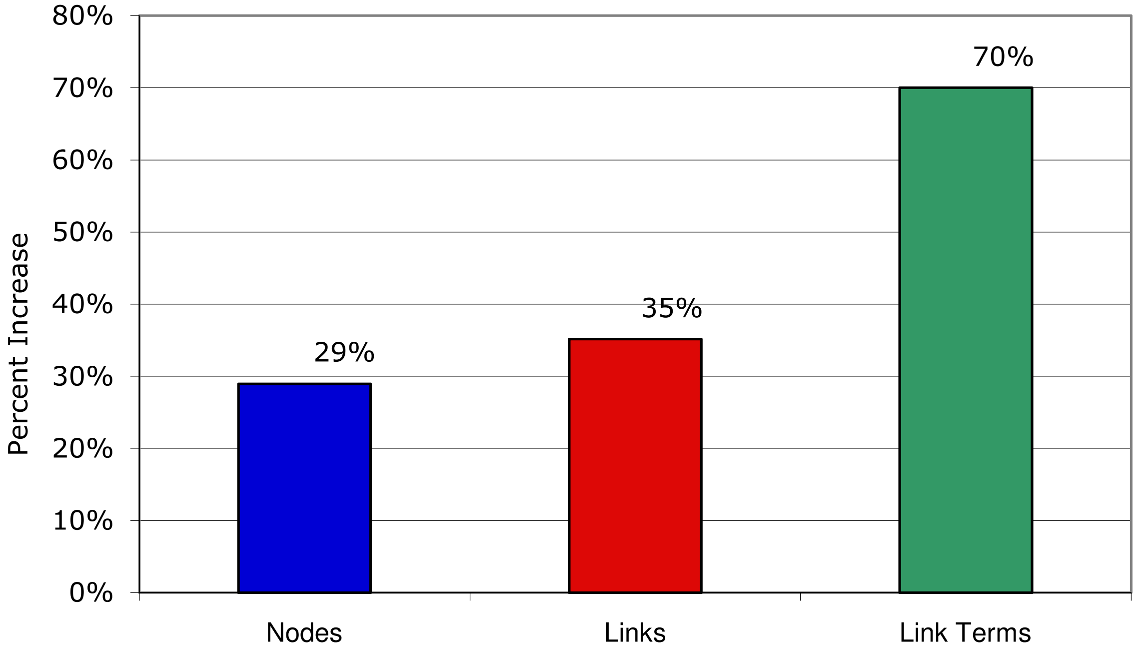


Figure IV. Percent increase of concept map component usage over the semester.

Ratios Comparing Concept Map Components

On the first day of class, students had a ratio of 2.93:1 links to link terms respectively, while by the final exam this ratio dropped to 1.36:1. Novak describes a concept map as a diagram where encircled concept nodes are connected by drawn links with terms to describe the relationship between concepts, which would give an expected ratio of drawn links with appropriate link terms to be 1:1 (2005). This definition suggests that students would properly label all links within their maps, to create an accurate scientific proposition, if they possess the appropriate level of literacy to articulate perceived relationships among scientific concepts. Data within this study shows distinct differences in student ability to accurately label links (see Figure V).

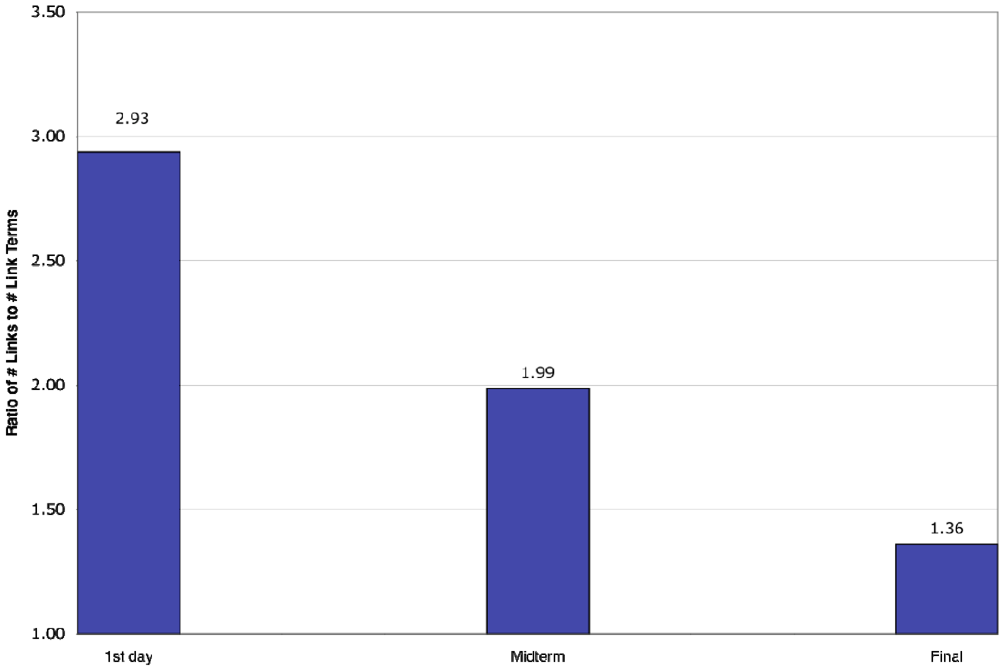


Figure V. Ratio of link term usage to links present in concept maps.

As students demonstrated gains in the mean number of both links and nodes within their concept maps, there is little difference in the ratio of the number of links used to the number of nodes used. Students maintained a ratio of 1.05 links per node at the beginning of the course compared to 1.16 links per node at the end of the course. Therefore, the number of links students utilized remained virtually unchanged during the semester, and it is how the links were used that showed measurable differences. As students changed how they used links within their concept map, they created different shapes of maps, observations of which were discussed earlier in regards to concept map graphical representation (see Table II).

Table II
Analysis of the ratio of student map component usage over one semester.

Map Component	1st Day (n=22)	Midterm (n=34)	Final (n=29)
Link	12.27	16.67	18.93
Link Term	4.18	8.39	13.93
Ratio	2.94	1.99	1.36
Link	12.27	16.67	18.93
Node	11.64	14.15	16.38
Ratio	1.05	1.18	1.16

Discussion

In examining the results from these samples, there appear to be significant changes in student concept map complexity in the first half the undergraduate science course, with students maintaining a consistent level of performance until the end of the term. As demonstrated by an increase in map shape complexity, from 13% to 35% by the midterm exam, students demonstrated more sophisticated interrelatedness of environmental concepts among concepts being studied in class. A drop in 7% of students producing complex maps during the final exam may be attributed to several reasons. Most obviously, students may have been making a less vigorous effort at the final day compared to the midterm point. Another possible explanation may be that students were changing the structure of their map from a network format to a hub & spoke format. There were more students, 37.9%, creating hub & spoke type maps on the final exam compared to 26.5 on the midterm (see Table I).

The most dramatic change observed in student-generated concept maps is in the increased usage of link terms with their maps. Link terms are integral for creating scientifically accurate propositions within concept maps and for displaying how a student articulates complex information about the topics being studied within class. These link terms identify the interrelationships necessary for linking two or more concepts together (Novak, 1991). If these link terms demonstrate an accurate relationship between the two topics the relationship is considered a *proposition* (Yin et al., 2005). As students generate greater understanding of the material studied within a particular class, their ability to generate propositions should increase (Novak, 1991; Yin et al., 2005). In this study, students on the first day of class, after having initial instruction on how to generate concept maps, had means of 4.13 link terms and 12.17 links per map. This demonstrates that students created propositions for roughly one third of links they could perceive between topics. This ratio of proposition formation, or the ratio of links to link terms, was 2.93:1 at the beginning and dropping to a ratio of 1.36:1 (see Table II), reaching close to a one to one ratio, and thereby increasing accurate propositions. Incorporating accurate proposition usage in concepts maps can be a means by which students demonstrate how they have created meaningful learning of what they have studied. Ormrod (2004) discusses how development of appropriate proposition usage provides students a mental model that helps in understanding relationships among concepts and storing knowledge in terms of the underlying meaning. Strike & Posner (1985) argue that the key for students to develop understanding of concepts studied in class lies in their interpretation of the essential meaning of new concepts within their own cognitive framework, and that ideas must function, psychologically, within some representation of a network of propositions. Following this line of argument, students within this study demonstrated their interpretation of the interdependent concepts within environmental science by creating more complex, networked concept maps, with an increase in scientifically accurate propositions, demonstrating a sophisticated and literate meaning of science content.

Conclusions

This study examined several questions concerning how students learn complex environmental concepts that emphasize the interrelationships among various scientific fields. Changes in the complexity of student generated, maps are significant, based on the measurements used within this study, from the beginning of the semester with little change at a midterm peak to the end of the semester. A linear increase in the mean number of nodes, links and link terms used within maps shows students are quantitatively increasing their knowledge, however, using structural methods of scoring may be limited in determining the true development of concept map complexity (Kinchin & Hay, 2001; Yin et al., 2005). A significant increase in proposition creation does demonstrate that students can better articulate their understanding of how nodes, key concepts, are interrelated.

Being able to articulate interrelationships is an important skill in demonstrating more sophisticated understanding of complex concepts. Rye and Rubba (2002) demonstrated this in their study examining how concept map scores correlated with student aptitude tests in California. Students who had high structural concept maps scores also had high California Achievement Test (CAT) scores and verbal scores. By increasing their usage of link terms to form propositions, students were more successful at articulation of the interrelationships among concepts they were trying to demonstrate through their concept maps. This points to two prongs of knowledge acquisition, one in the form of sophisticated understanding of interrelationships among environmental concepts, and the second in the ability of students to articulate these relationships. Therefore, the most prominent development in this study was observed in proposition creation and articulation of interrelationships of concepts. If assessment is a teacher’s, or researcher’s, attempt to examine how a student understands what they have studied, then using techniques such as rapid assessment categorization plus component usage of concept maps can be an effective teaching and assessment tool in science courses for all age levels.

Ormrod (2004), summarizes many learning theorists when she explains how students integrate new knowledge into long-term memory through meaningful learning by storing new propositions with related propositions in a network of concepts. If knowledge acquisition and retention is an important end goal of education, then students generating complex concept maps, with accurate propositions are demonstrating literate, meaningful learning.

Limitations & Further Study

There are several limitations within this study that can be observed. A primary limitation is the use of concept maps as a graphical measure of literacy and knowledge acquisition. A previous method of measuring what a student knows or has learned is the traditional paper and pencil assessment, which provides for ease of quantitative analysis. However, this study attempts to bring another method of quantifying student’s knowledge acquisition through examination of their hand-drawn concept maps. Since a comparison of standard assessment data or student grade achievement and their individual concept maps is outside the purview of this paper, there is room for debate on how complex maps demonstrate increased student literacy or earning.

Another limitation within this study is in the subjective nature of classifying each of the student's concept maps into graphical categories, described by Yin et al. (2005). It is difficult to classify the graphical concept maps without clear explanation as to how each of the different categories is defined. For example, the investigator had to decide if a map was a hub and spoke, circular, or complex format when the shape of the map would be a central idea with many outside nodes connected to the central topic but outermost nodes were connected by unidirectional links, in essence forming a true wheel with hub, spokes and rim (see Appendix C). Or would this particular map be better categorized as complex, since there are cross-links but the map itself does not form a true network? This ambiguity caused several of the maps to have the possibility of being categorized into different groups, and thereby influencing results. There also needs to be further research in quantification of concepts to clearly define the parameters by which maps are accurately assigned a graphical categorization.

Another limitation was precision when measuring the number of links and link terms. As concept maps become more complex and the number of nodes, links, and link terms increased, reading the hand drawn maps becomes more difficult, a result of the immense differences in handwriting quality and length of link lines separating node topics. If students have large, irregular handwriting and short link lines between node topics, the appearance of the map can become quite crowded and the lines of distinction become blurred. This can cause differences in measuring each of these components, since some propositions may be missed or misidentified as nodes. This is where computer generated concept maps would greatly assist an instructor or investigator measuring various components within maps. However, as Royer and Royer (2004) determined in their study comparing hand drawn and computer generated maps, students created far more complex maps while working by hand than they did when using computer software.

In analysis of concept maps, the investigator considered different methods of quantifying the relationships among various components found within student concept maps. There are many methods of scoring and identifying the complexity of concepts maps left unstudied. Developing expert-based maps for each of the topics students used to construct their maps would be an important analysis on the development of student knowledge towards expert-level comprehension. There is a need for studies into the accuracy of the relationships identified by students within their maps and if students increase the accuracy of their links between nodes. This information may shed light on the development of knowledge by students as they generate more complex concept maps.

Lastly, construction of these maps had very open parameters under which the students had to work. The students were not directed to have a specific number of nodes, links or link terms. Also, the students were not directed to construct their maps in any prescribed form either hierarchical or non-hierarchical. The only directions given to the students included that they choose subjects from a list of topics studied, create as complex a map as they could, given their knowledge of their subject choice, and be sure to label their links with appropriate link terms. How students chose to follow these directions was up to them, and there is evidence that some students chose not to hand in their maps, which influenced sample sizes during the semester. Students are individuals who are free to think and act independently, this study focused on observing a glimpse at how their minds work.

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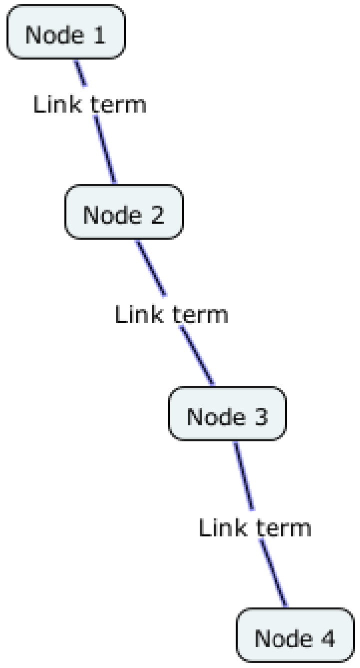
Appendix A

Concept Map Shape Exemplars Using Florida Institute for Human and Machine Cognition (IHMC) CMapTools® computer software

Linear Concept Map



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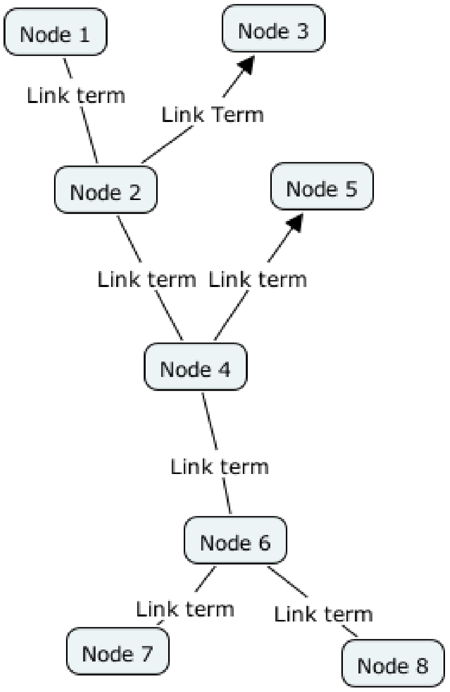
Tree Concept Map



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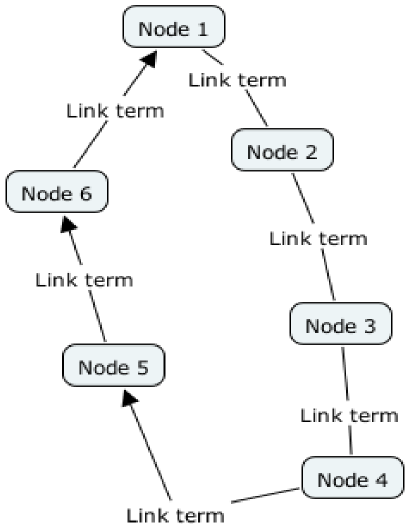
Circular Concept Map



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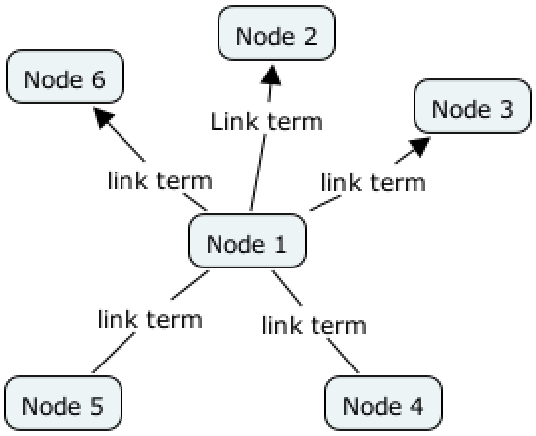
Hub & Spoke Concept Map



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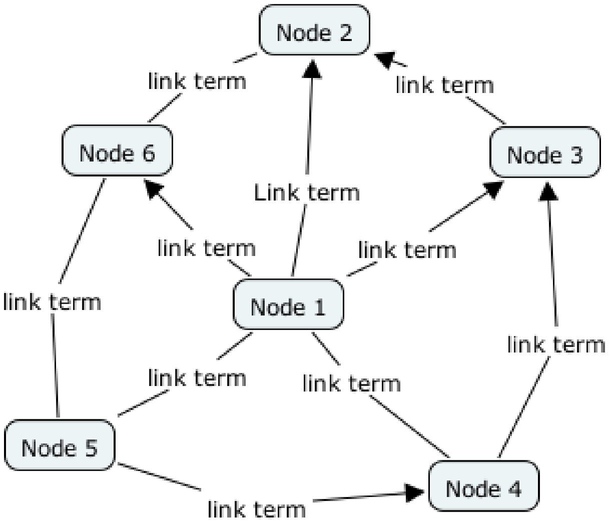
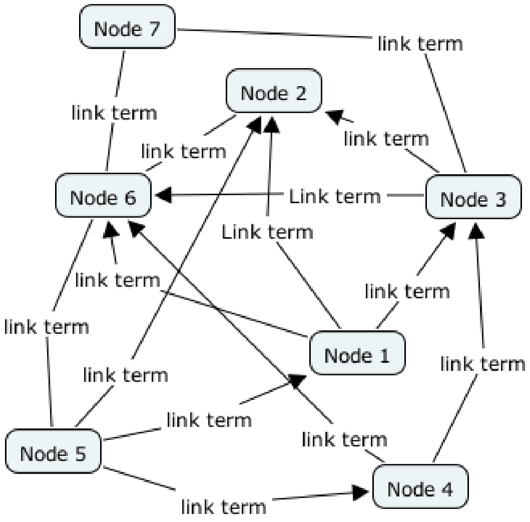
Complex Style Concept Maps Drawn with Florida Institute for Human and Machine Cognition (IHMC) CMapTools® computer software.

Wheel Concept Map



Network Concept Map



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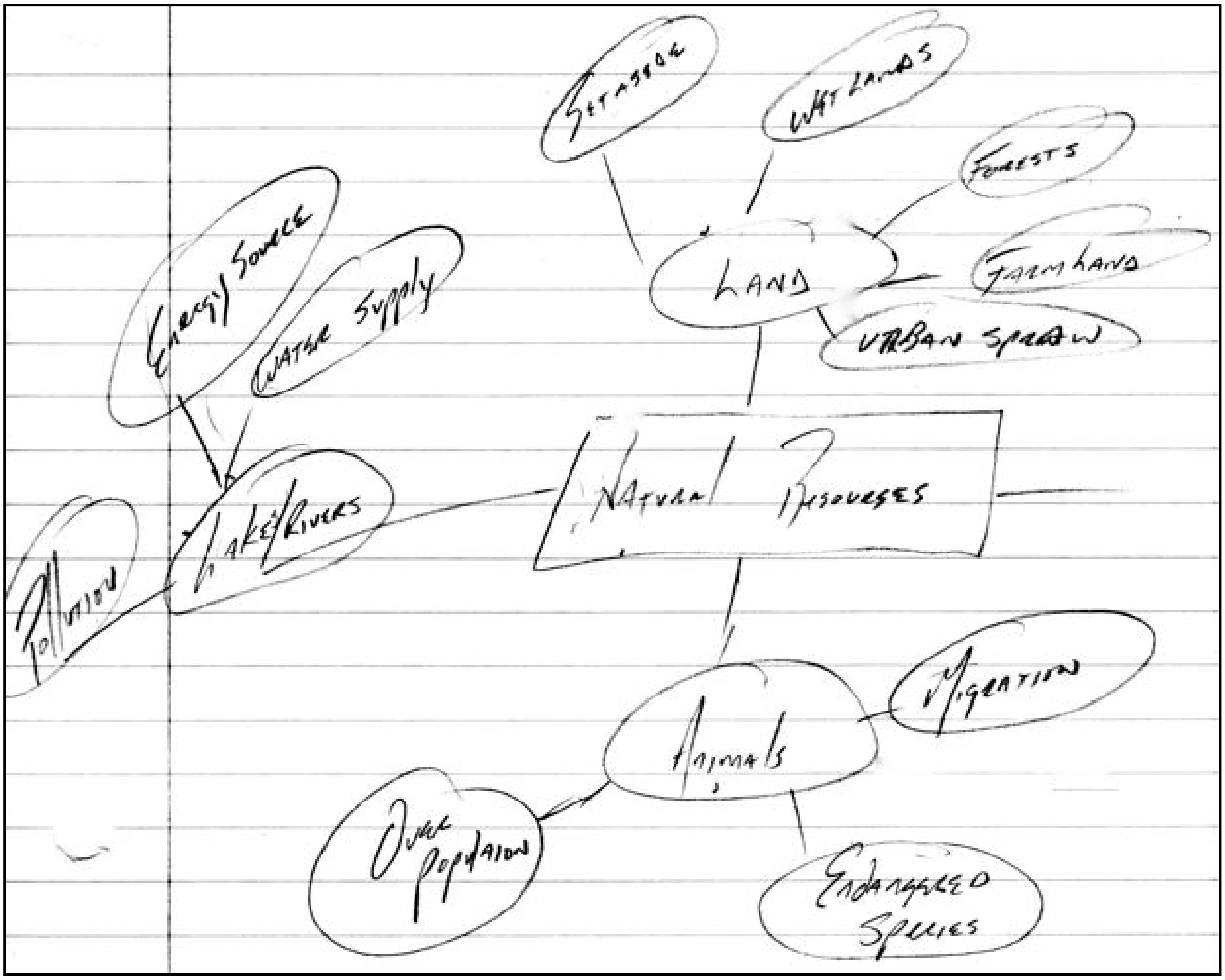
Appendix B

Student 1 on 1st day of class



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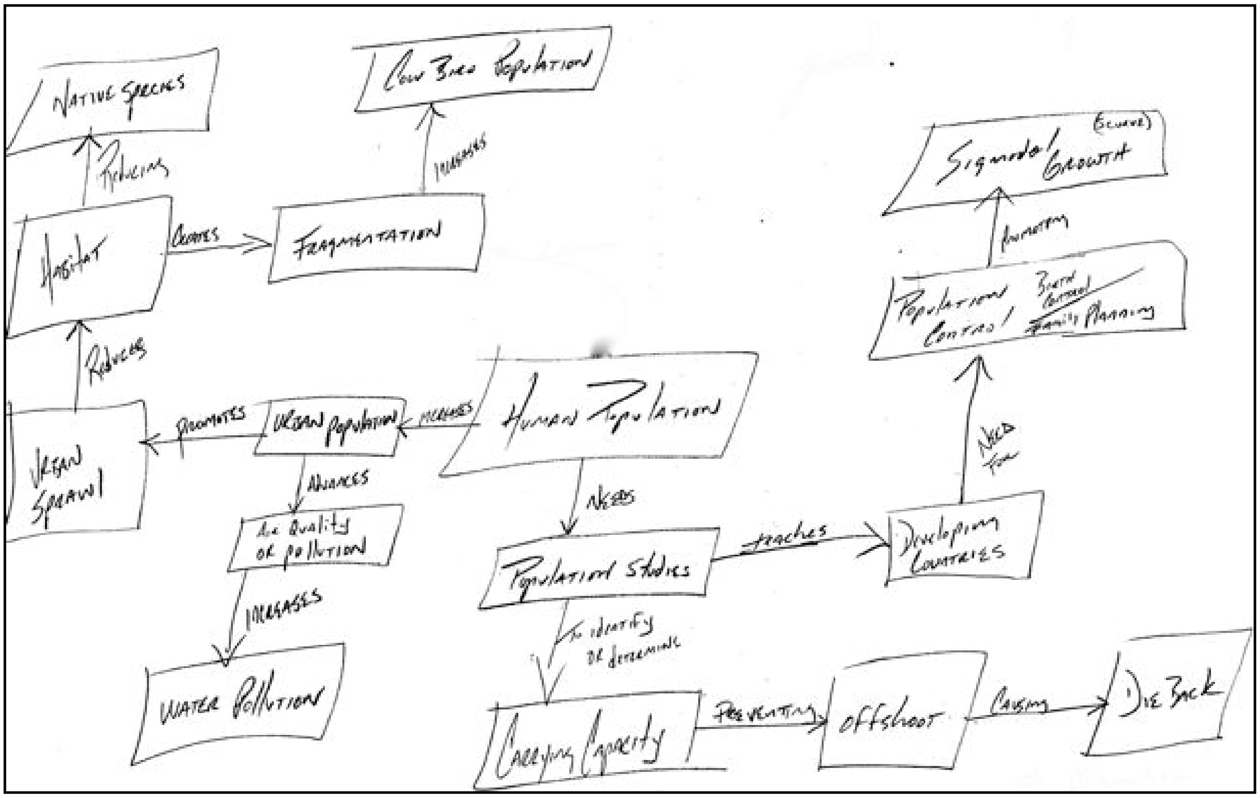
Student 1 at midterm



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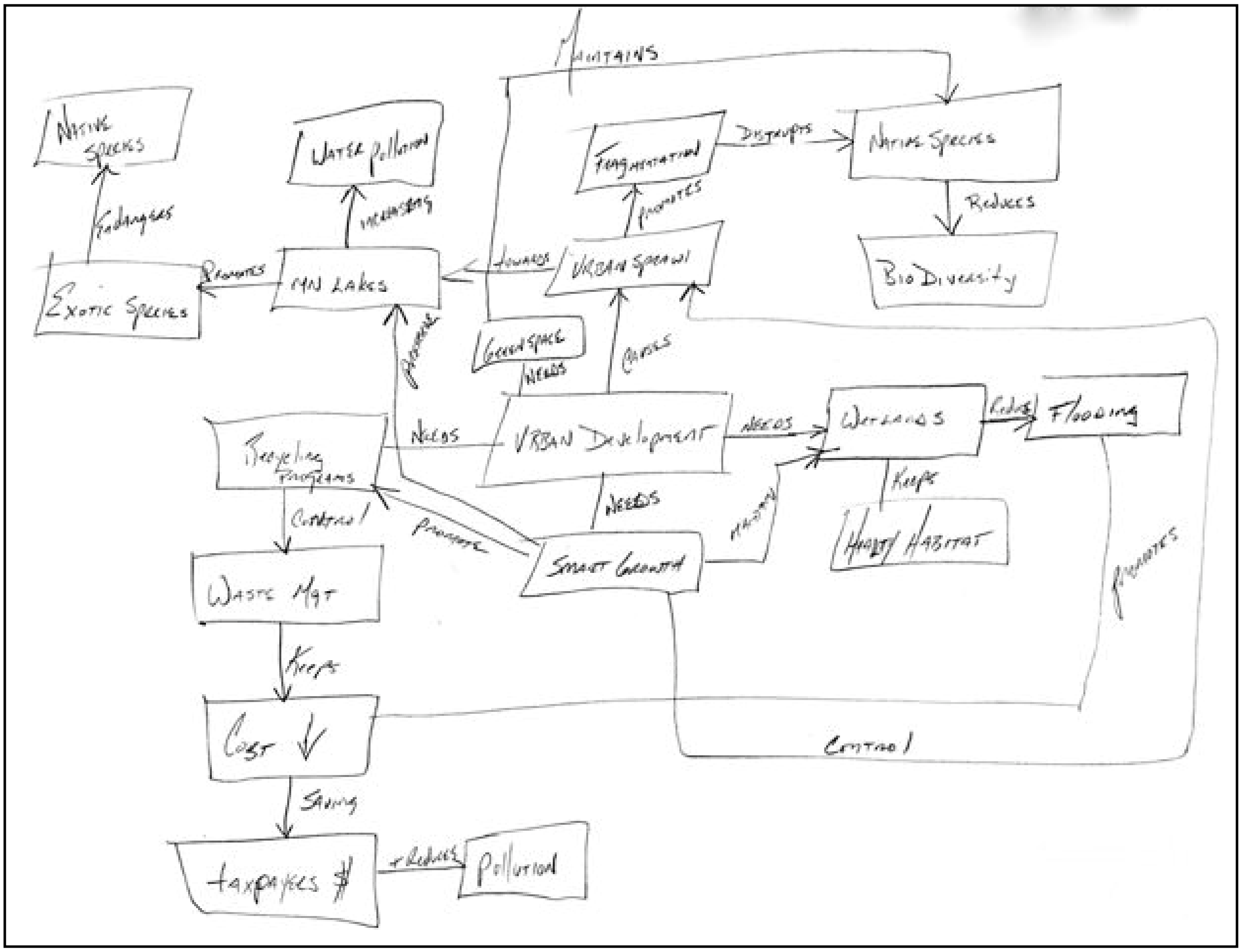
Student 1 on final day of class



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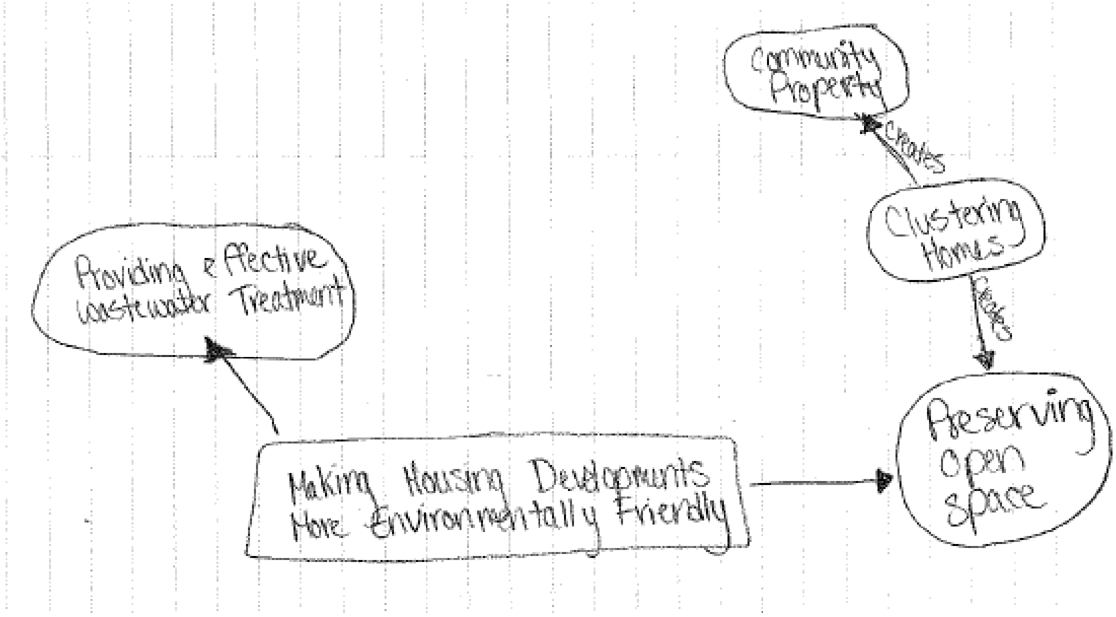
Appendix C

Simple Concept Map Exemplars From 1st Day of Class

Linear



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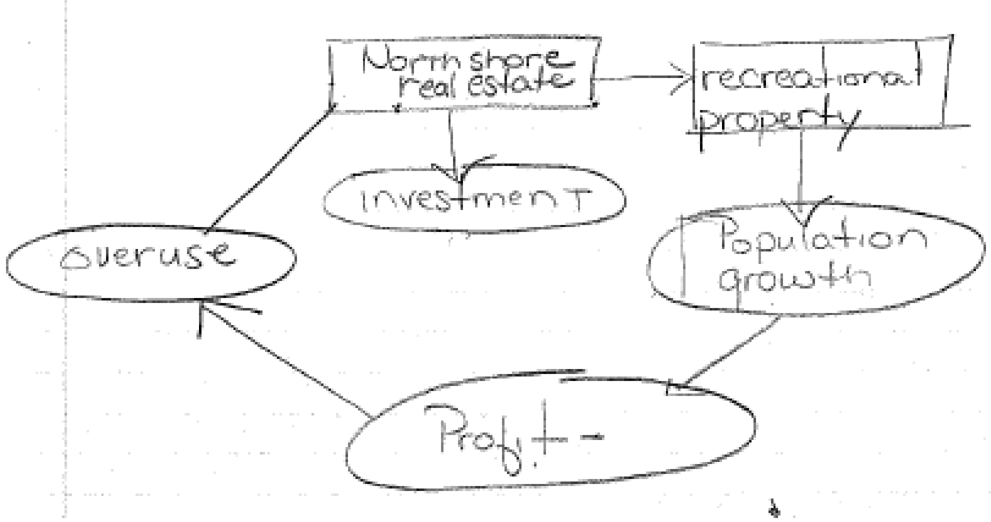
Circular



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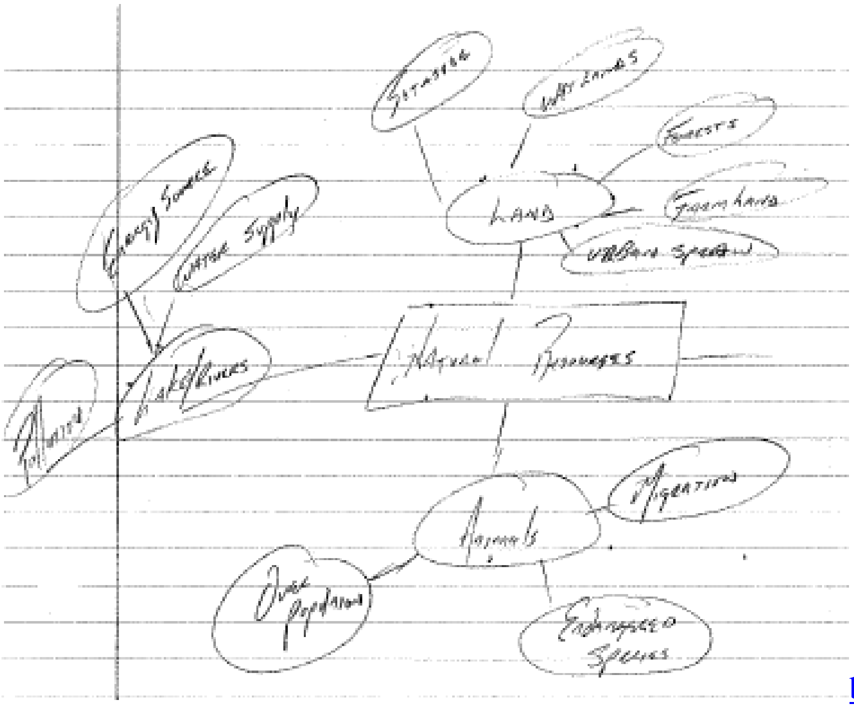
Tree



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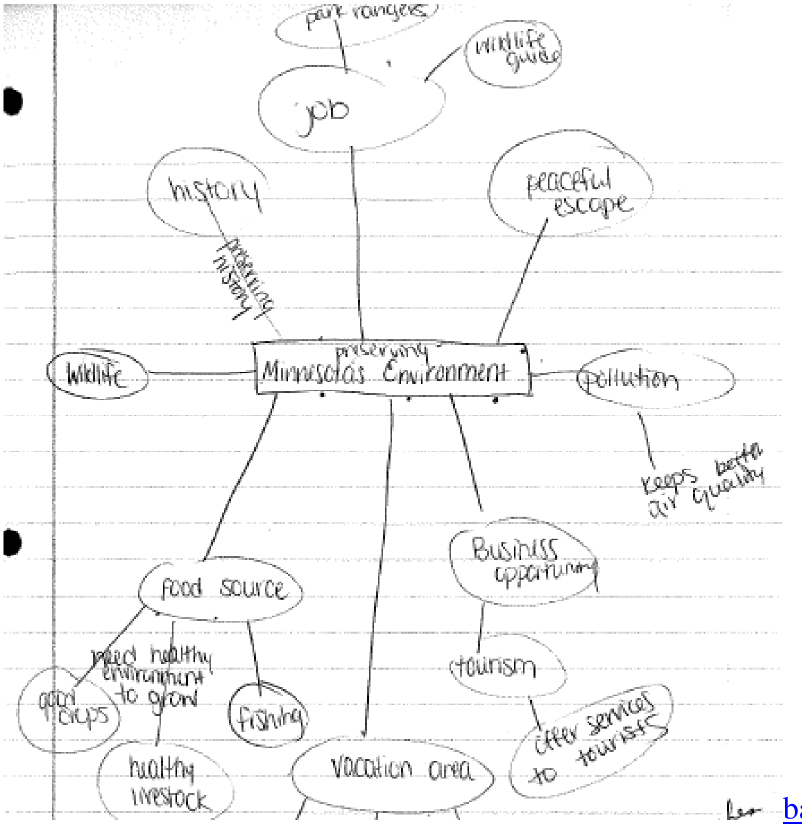
Hub & Spoke



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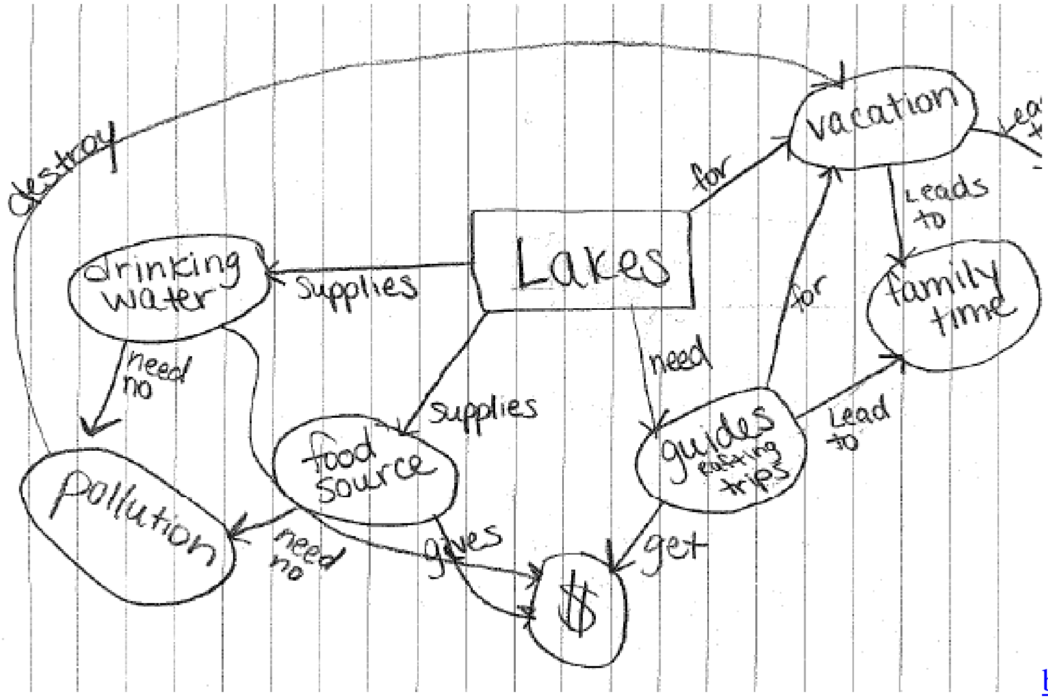
Complex Concept Map Exemplars From 1st Day of Class

Wheel



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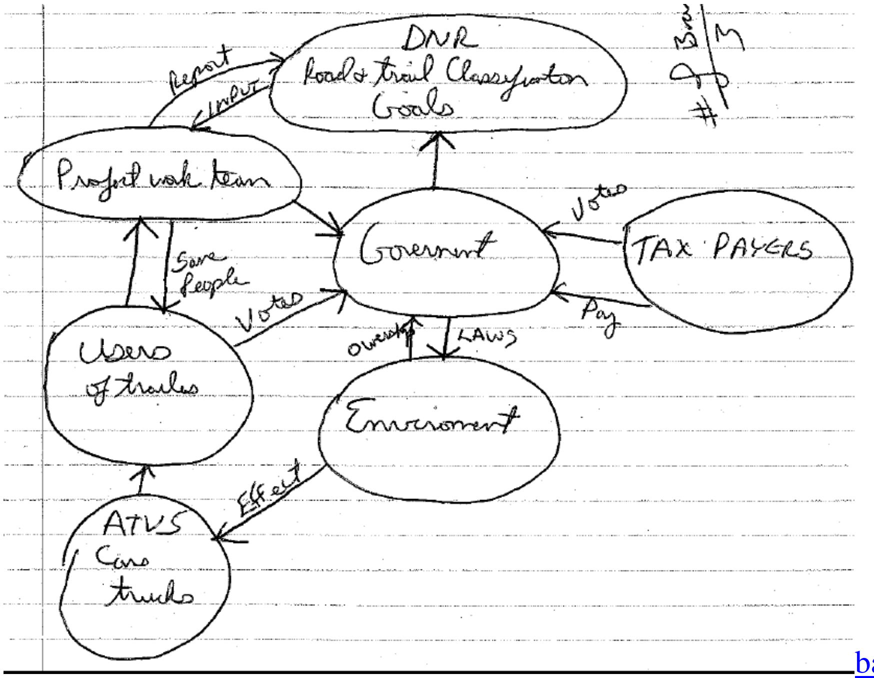
Network



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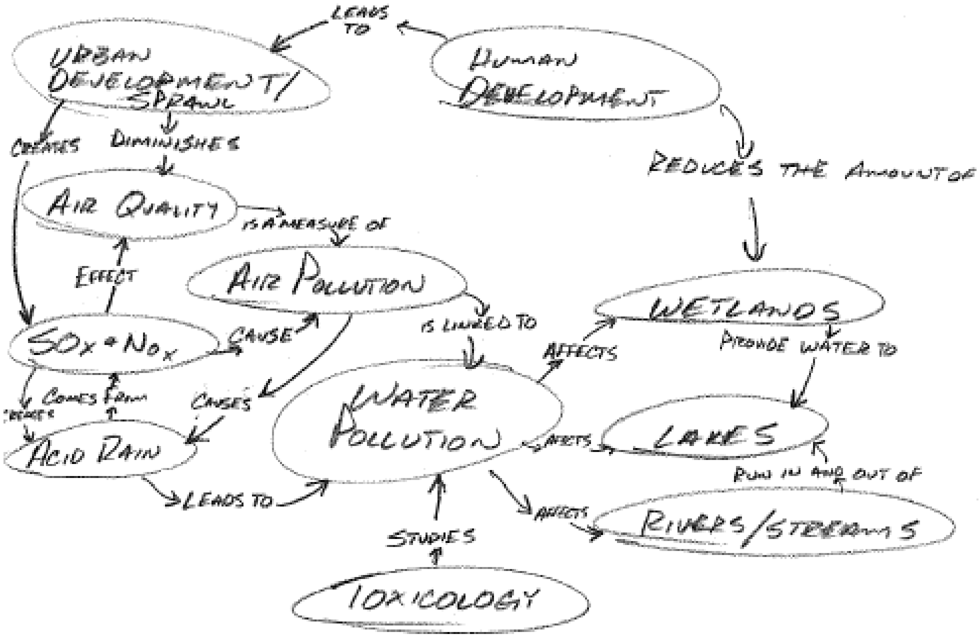
Appendix D

Complex Concept Map Exemplars From Final Day of Class

Network



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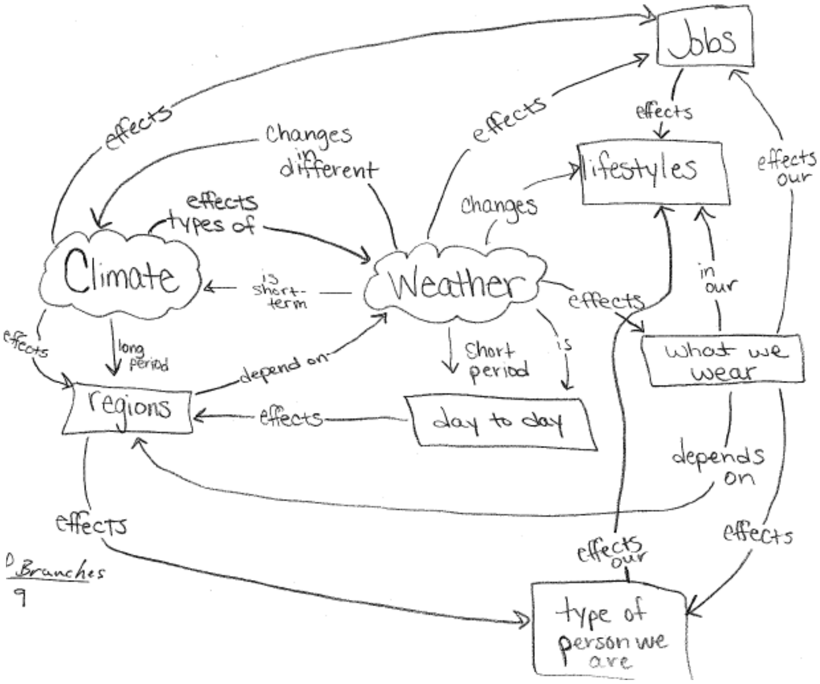
Wheel



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