Assessment of Systems Learning in an Undergraduate Civil Engineering Course using Concept Maps

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Abstract
As part of ongoing assessment of student learning in a new undergraduate civil and environmental engineering course, faculty members at the University of Wisconsin-Platteville have developed a concept map instrument. A major goal of the new course is to introduce students to infrastructure and help them understand civil and environmental engineering in terms of interconnected systems. In fact, the course was originally designed and added to the curriculum in an effort to help students think of the civil and environmental engineering profession as an integrated whole, rather than as distinct sub-disciplines that are taught in separate courses. Based on these goals of the course, concept maps were ideally suited to evaluating the systems-wide perspective that students are intended to gain.

This paper provides background on the new course, documents the theory and application of concept maps in assessment, and describes how the concept map assessment instrument was used to evaluate student cognitive gains in the course. Results of the concept map assessment show that the course is helping students to think more holistically about non-technical and societal aspects of engineering; however, students showed minimal gains in identifying various types of infrastructure in the built environment.

Background
The infrastructure of the United States is exceeding its design capacity, requiring extensive maintenance and renovation. In order to meet this challenge, a need exists to produce civil and environmental engineers who have a broad understanding of the pressing needs of the infrastructure of the United States and who can solve problems from a systems perspective. With this need in mind, the faculty of the Civil and Environmental Engineering (CEE) Department at the University of Wisconsin-Platteville recently created an undergraduate course that introduces students to infrastructure and helps them understand civil and environmental engineering in terms of interconnected systems.

The course is intended for sophomore students, and is typically one of the first courses students take from the CEE Department. Two of the primary goals of the course are:

1. To introduce the students to the subdisciplines of civil and environmental engineering while emphasizing the interconnectedness between subdisciplines, and

2. To help students think holistically about civil and environmental engineering, including non-technical and societal aspects of engineering.

There are other goals of the course, but this paper will be restricted to discussing the success of the course in meeting these two goals. Further background on the course can be found in previously published work.[1,2,3,4]

In order to assess the effectiveness of the course in meeting the goals listed above, a concept map assessment instrument was developed. Concept maps are diagrams that provide a means of organizing knowledge within a domain by identifying key relationships between concepts in the form of propositions. Novak and Gowin define a concept as “a regularity in events or objects designated by some label” and propositions as “concept labels linked by words.”[5] In a concept map, concepts are enclosed in circles or boxes with lines linking related concepts together. A word or phrase is written with the linking line indicating the relationship between the concepts. For illustrative purposes, a concept map about concept maps is shown in Figure 1.

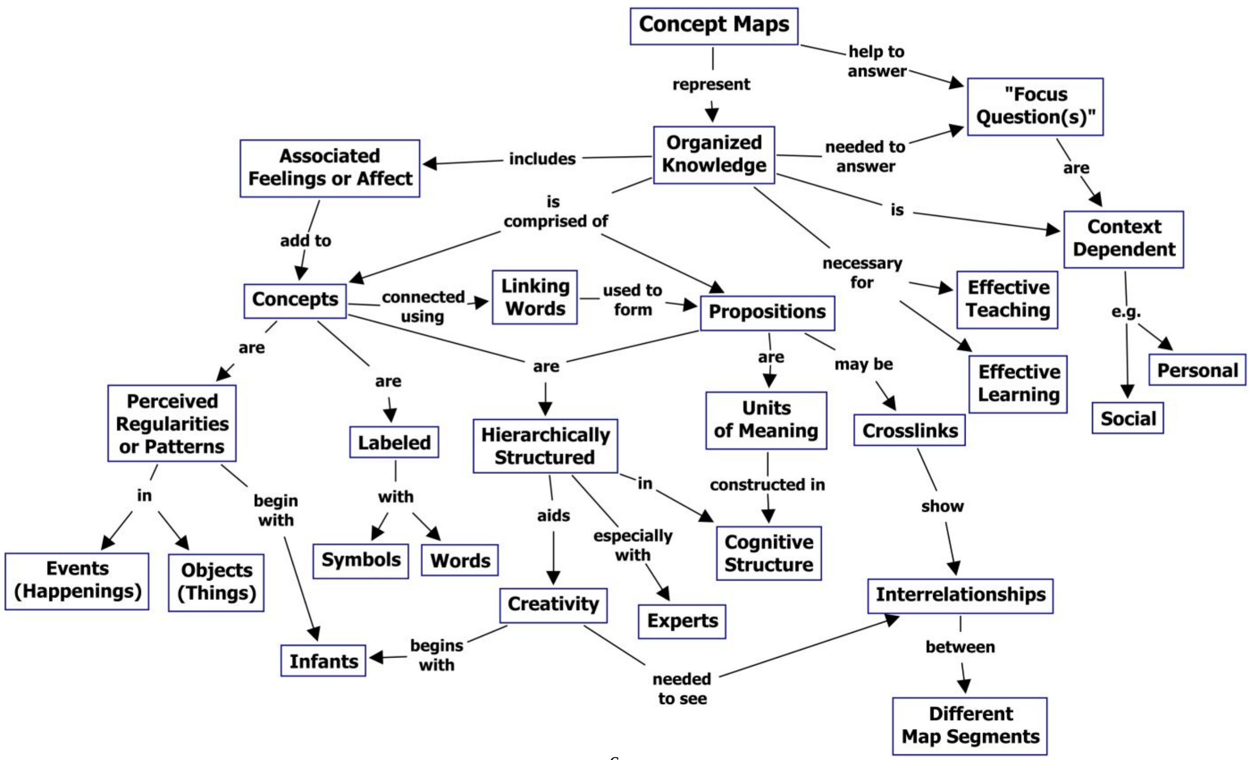

Figure 1 - A concept map about concept maps.[6]

In addition to being used for assessment of student learning, concept maps are useful tools for helping students understand the structure of knowledge and how knowledge is produced within a content area. Grounded in cognitive learning theory[7], concept mapping promotes deep, meaningful learning, rather than superficial, rote learning as students relate new concepts and propositions to relevant existing knowledge schema.[8] They can be used by students as a study tool, and by instructors for enhancing teaching, facilitating curriculum planning, and as an assessment of student learning.[9]

Concept maps are typically created through a series of steps.[6] These include (a) defining the topic or focus question; (b) identifying the key concepts that apply to this domain; (c) ordering concepts from general to specific; (d) drawing links between concepts; (d) creating phrases that describe the link; and (e) cross-linking concepts in different segments or domains of knowledge on the map. When used for assessment, they can be scored quantitatively through techniques involving counting of concepts, links and propositions and qualitatively based on the overall morphology of the map.[10,11]

Concept Mapping for Assessment of Student Learning

Since the early work of Novak and Gowin,[5] concept maps have been used for assessment across disciplines and across grade spans. Concept maps have been used in secondary science and geography classes,[12,13,14,15] in teacher education,[16] graduate educational psychology,[17] and nursing education classes,[18] among others. Novak noted that concept maps can be applied to any subject matter domain or topic within a domain.[19] While used most commonly as an instructional tool, the effectiveness of concept mapping for assessment purposes has been documented in numerous studies across multiple disciplines. Instructors and researchers have found concept mapping to be useful for: examining student understanding of connections among concepts in a subject; uncovering the nature of students' misconceptions; and for examining change in students' ideas about a topic and how those ideas change as students modify existing knowledge and prior misconceptions through the process of meaning-making.[19,20]

As a visual representation of knowledge, concept maps allow instructors to easily scan for key concepts and relationships while also examining changes in structural complexity over time.[21] As an advantage over more traditional means of assessment, concept maps allow for the portrayal of knowledge as "an integrated network, rather than a collection of facts."[9] Additionally, concept maps serve as a means to determine correspondence between novice and expert understanding of a given subject.

Walker & King conducted a study wherein undergraduate students (sophomores and seniors), doctoral students and professors constructed concept maps identifying ten to twenty most important concepts in biomedical engineering and how they are related.[22] They found that faculty (expert) maps showed evidence of a greater degree of synthesis and application of knowledge thus portraying how knowledge is transformed from novice to expert learners.

In their study of secondary students in engineering education, Daugherty and others noted that the use of concepts maps as pre and post measures revealed the progression of students' understanding "from a definitional understanding of a concept (the what), to being able to provide a richer explanation of the concept with examples (the why), to being able to articulate its applications (the how)."[23] Pearsall and others used a concept mapping assessment at four successive time periods over the course of a semester in a college-level biology class.[14] The authors found that concept maps were a means to document progressive changes in the structural complexity of student understanding of content as evidence by statistically significant increases in mean number of concepts, relationships and cross-links from the beginning to end of the course. Green and others used concept maps as a pre/post measure of science teachers' content knowledge while participating in professional development involving a research experience with scientists.[16] They also saw changes in knowledge through an increase in number of concepts and relationships and also in the accuracy of propositions with students showing a "more expert-like" level of knowledge at the end of the research experience. Walker & King found that students in an undergraduate bioengineering class showed not only a greater number of concepts and connections from pre- to post-testing with concept maps, but also noted that on the final concept maps, students used more precise vocabulary and created more coherent mapping structures than on the pretest.[22] These studies, among others, show the efficacy of concept mapping as an assessment tool to understand the changes in depth of knowledge among learners.

Limitations to Concept Maps as Assessment Tools

Researchers have noted some limitations to the use of concept maps for assessment purposes. Included among these are time to develop student proficiency at the task, variations in the concept mapping task and scoring systems, and questions related to reliability and validity.

The level of cognitive effort needed to become proficient at concept mapping suggests that students need practice with learning how to construct maps prior to using them to assess understanding.[24] This involves devoting instructional time to teaching students how to construct concept maps so that those used in assessment are reflective of what they know and understand rather than how sophisticated they are at constructing a concept map overall.

Concept mapping tasks can vary from having students create a map from scratch, to giving students skeleton maps with some concepts included, to providing a list of concepts and asking students to create a map from the list. Variations in scoring systems also exist. While some emphasize a more qualitative approach based on the overall morphology of the maps to indicate students understanding, other approaches are highly quantitative with detailed scoring systems involving counting of nodes, links and propositions, sometimes weighting scores on certain aspects of the map to award more points for different characteristics.[10] Scorers must decide on the criteria for map creation and scoring and then train others who may be involved in the scoring process to establish inter-rater reliability. Additionally, scoring concept maps requires a deep conceptual understanding of the material covered in the maps and therefore requires the input of experts to judge the map components and the relationships among concepts.[25] This can be a time-consuming endeavor involving the development of scoring criteria and a process for judging the validity of concepts and relationships.

A limited number of studies are available related to the reliability and validity of concept maps for assessment.[25] Zeilik noted that "because [concept maps] probe an individual's or a group's cognitive organization, they are very idiosyncratic and difficult to compare, either among individuals or groups, or across time for the same individuals or groups."[20] Issues of construct validity (the degree to which an assessment measures what it purports to measure) have included concerns that concept maps measure different aspects of knowledge than traditional assessments and that the degree to which they can predict performance on skills related to those involved in the mapping assessment is variable. However, Cañas et al. noted that from a review of available studies, the reliability and validity measures indicate "concept maps fall within acceptable ranges from the viewpoint of psychometrics."[25]

Methodology

In this study, a concept map instrument was developed and administered prior to the start of the semester (pre-test) and at the end of the semester (post-test.) In both cases the students were asked to create a concept map using the focus question "What is infrastructure?" The pre-test was e-mailed to the students before class had started and student work was required to be uploaded to the course management system before the first lecture period. The post-test was administered as a take-home portion of the final exam. Both the pre- and post-test instructions to students are included as Appendices 1 and 2. No class time was used to teach students how to create concept maps (as recommended by Klassen[24]); however, the instructions for both the pre- and post-test included a lengthy description on how to construct a concept map.

The concept maps were scored using a quantitative approach by adding the number of concepts or links in the following six categories:

1. The number of concepts mentioning infrastructure "components" (e.g., roads, bridges, wastewater treatment plants, etc.),

2. The number of infrastructure "sectors" (transportation, structures, flood control, etc.) listed as concepts or implied by the infrastructure components,

3. The number of *correct* links between technical concepts (infrastructure components, infrastructure sectors, or engineering concepts),

4. The number of concepts for non-technical aspects of infrastructure (e.g., economic growth, ethics, pollution, etc.),

5. The number of *correct* links between a non-technical concept to any other concept, and

6. The number of engineering concepts (e.g., constructability, design, resilience, etc.).

The detailed instructions for scoring the concept maps are included in Appendix 3.

Initially, we planned to have the concept maps scored by a trained evaluator who did not have extensive civil engineering infrastructure expertise. However we found, similar to Cañas et al.,[25] that deep conceptual understanding was needed and so course instructors completed the scoring of the concept maps. The results presented here come from the Spring 2013 offering of the course, which had two sections of the course taught by two different instructors. One of the instructors scored all of the concept maps.

Of 56 students enrolled in the class, 49 completed both pre- and post-test concept maps that could be scored. We could not score 7 of the concept maps because two students did not submit the pre-test, three students did not complete the post-test (they dropped the course or did not take the final exam), one post-test was illegible (the concept maps were submitted electronically), and one student inexplicably submitted a pre-test concept map about the human body (possibly copied from another source).

Results

The evaluation of the pre- and post-test concept maps followed Pearsall, Skipper & Mintzes[14] in determining the statistical significance in the gain of the number of concepts and links. The radar chart in Figure 2 shows the average student pre-test and post-test concept map scores for each of the six categories. Table 1 gives the results of a student's t-test analysis using the hypothesis that concept map scores would increase from pre- to post-test.

The findings from the data analysis are:

- Average student scores improved in each of the six categories from pre-test to post-test.

- The increase in the number of infrastructure components identified and the increase in the number of non-technical links were not statistically significant ($p > 0.05$).

- The increase in the number of infrastructure sectors identified was statistically significant ($p < 0.05$). However, on average, students did not identify a large number of infrastructure sectors on either the pre- or post-test. Out of a total of 12 infrastructure sectors presented during the semester, students identified on average 3.7 sectors on the pre-test and 4.3 sectors on the post-test with a standard deviation of 1.9 in both cases.

- There were statistically significant gains in the number of technical links, non-technical aspects, and engineering concepts ($p < 0.001$ for each of these categories) identified on student concept maps.

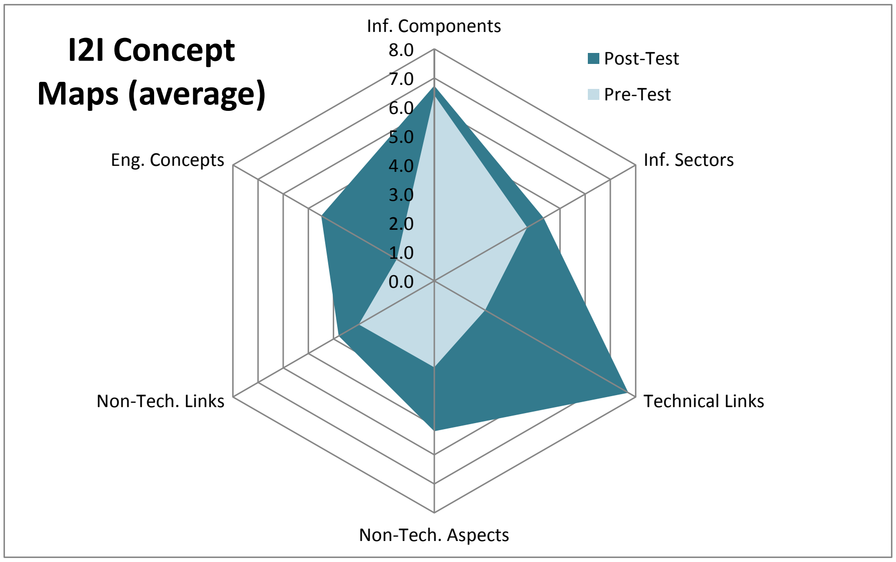

Figure 2 - Pre- and Post-test concept map average student scores for the six categories (n=49).

Table 1 – Average student scores and *p*-values for the gains in each concept map category (n=49). The p-values were calculated using a student's t-test (one-tail, paired).

Concept Map Category	Pre-test	Post-test	
Infrastructure Components	6.4	6.7	$p > 0.05$
Infrastructure Sectors	3.7	4.3	$p < 0.05$
Technical Links	2.0	7.7	$p < 0.001$
Non-Technical Aspects	3.0	5.2	$p < 0.001$
Non-Technical Links	3.0	3.8	$p > 0.05$
Engineering Concepts	1.5	4.5	$p < 0.001$

Conclusions and Future Work

The results of this concept map assessment lead to the following conclusions.

- The large and statistically-significant gain in the number of technical links indicates that the course is helping students to see connections between the technical areas of civil engineering and infrastructure. Helping students to see these connections was a primary goal of the course.

- The statistically-significant increase in the number of non-technical aspects of infrastructure identified by students on their concept maps indicates that the course is helping students to achieve the course goal of thinking holistically about non-technical and societal aspects of engineering.

- The small gain in the number of infrastructure sectors identified was somewhat disappointing. This seems to indicate that students are not becoming more aware of the various types of infrastructure found in the built environment. As can be seen in Figure 3, a very high percentage of students identified infrastructure in the transportation (roads, highways, etc.) and structural (buildings, bridges, etc.) sectors. This seems to indicate that we are focusing too much on the more prominent aspects of the infrastructure in the course materials.

- While there was an increase in the number of non-technical links on the student concept maps, the increase was not statistically significant. This would suggest that instructors need to be more explicit about making connections between course modules, particularly concerning non-technical aspects.

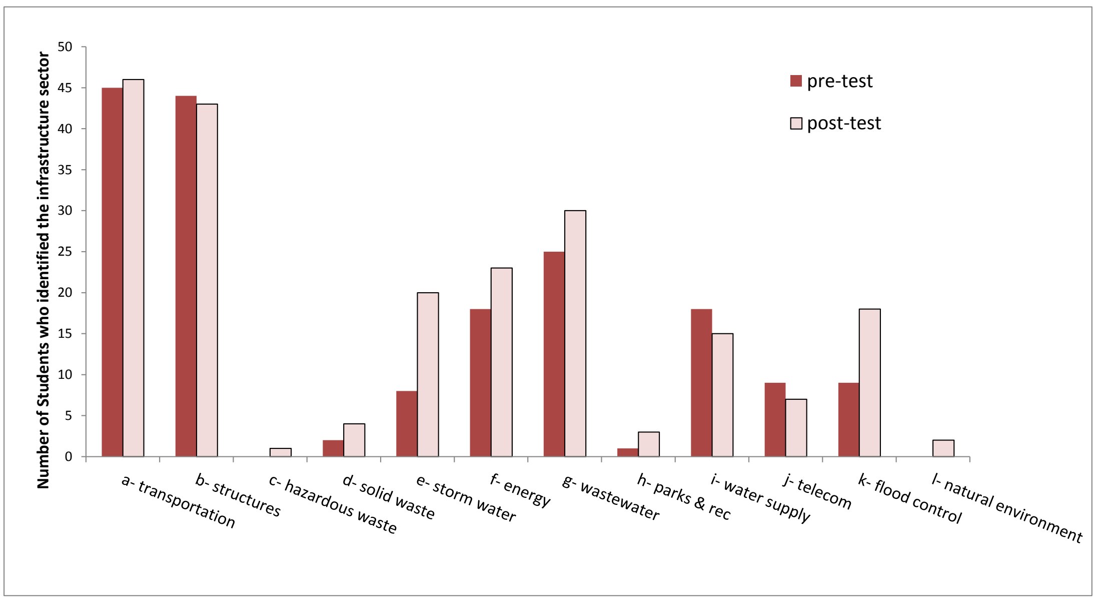

Figure 3 - Sectors identified on student concept maps (n=49)

The concept map instrument was helpful in assessing student knowledge and gains with respect to infrastructure and the connections they are making between technical and non-technical aspects of engineering. Going forward, three specific areas will be pursued by the authors.

1. The reliability and validity of the instrument will be investigated. For the current work, one instructor coded all pre- and post-test concept maps. In future work it is anticipated that a much more detailed process for scoring the concept maps will be needed to ensure inter-rater reliability.[10]

2. The concept map scoring process will be refined to determine gains in the accuracy of propositions and increases in the accuracy of the vocabulary used by the students.[16,22]

This would provide a richer understanding of how student conceptions of infrastructure change by completing the course.

3. Materials from the course and from a similar course at the U.S. Military Academy will be implemented at six other universities through a funded NSF grant. The concept map instrument will be used at these other universities, which will generate additional data on student development. The effectiveness of the instrument in other settings will also be evaluated.

Acknowledgements

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CIVILENG 2000 Hw 1A – Infrastructure Concept Map (Preconceptions) Due: January 23, 2013 **before class**

Introduction

The objective of this assignment is to evaluate how much you understand about infrastructure. At the end of the semester, you will be given a similar assignment. As a result, the faculty teaching this course will be able to evaluate how well the course has met its objectives. Thus, it is imperative that you complete this assignment by yourself and that you give it your best effort.

Guidelines

Do NOT do any research to complete this assignment! Please do not even browse through the textbook! Do not discuss your ideas with other students before creating your map. Your homework score will not depend on the "correctness" of your results.

Instructions

The concept map you are to complete is intended to answer this focus question: "**What is infrastructure**?" Be sure to follow all of the instructions below carefully.

- List as many "key concepts" as you can that are related to the focus question.
- Arrange these concepts using the tool on https://bubbl.us/. A video is available to show you how to use Bubbl software (see the content -> Lectures section on D2L). Reminder: you should not be reviewing any of the other items posted on D2L when you view this video as you have already begun the problem by this point.
- Draw cross-links between the concepts (lines between two bubbles/concepts). For each cross link, add "linking words" that describe how the two bubbles/concepts are related. The concepts should be one or two words, but not phrases.
- When you are done with your map, print it as a pdf and submit that pdf file to the dropbox on D2L (Learn@UW) **before our first class on January 23**. It is very important that you name your file as such:
  HW01A_ [section #]_[last name]_[first name].pdf
  For example, Ben Bocher in Section 01 would name his file "HW01A_01_Bocher_Ben.pdf".

See the example on the next page.

Evaluation of Your Results

This question will be evaluated based on the following criteria (among others):

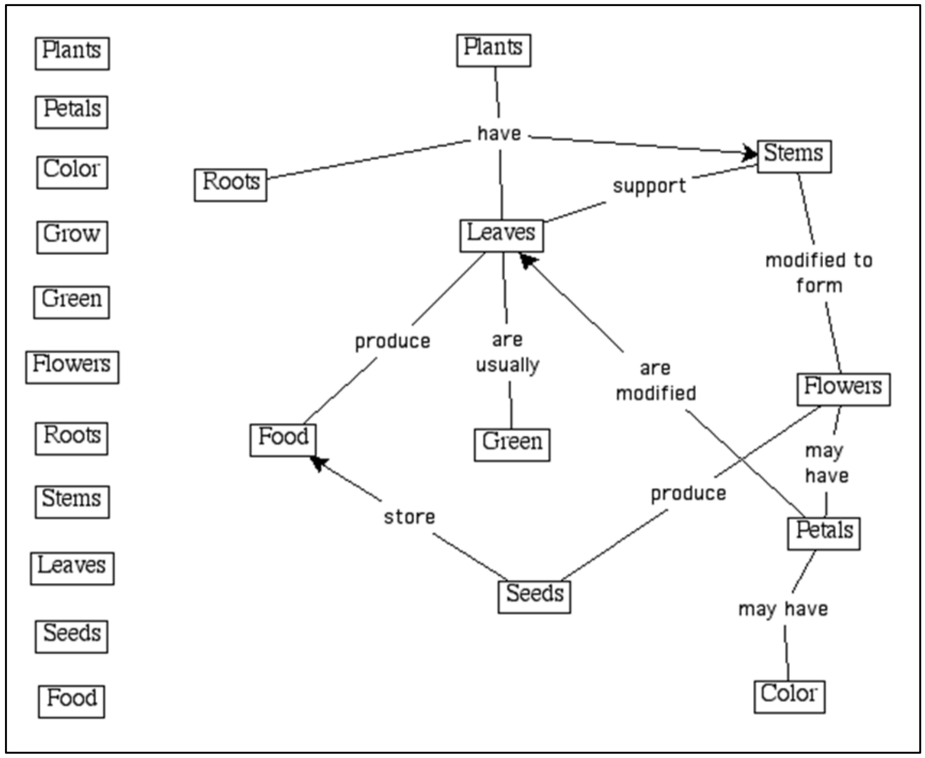
- The number of concepts (bubbles) you come up with
- The variety of concepts you come up with
- The number of links (lines and arrows) you come up with (**linking words are required**)
- The variety of links you come up with
- The factual correctness of the links you come up with
- The neatness and legibility of your work (check to make sure that when you print your result, the words are clearly readable, text is not too small, links are clear, bubbles do not overlap and obscure one another, etc).

The grade you receive on the assignment will depend only on how well you followed the instructions above, not on the "correctness" of your results.

When you are done with your map, **print your concept map as a pdf** and submit that pdf file to the dropbox on D2L (Learn@UW). Also, print out a hardcopy of your map and bring it to the first day of class.

Example:

The idea of concept mapping may be best understood with the example to the left (source: https://www.msu.edu/~luckie/ctools/). Consider the following (simple) concept map that answers the question "What is a plant?" To the left of the concept map is a list of concepts, and these have been arranged in the map. Note that there are a very large number of possible concepts that could go in the list of concepts; these concepts can be arranged in any number of ways; the concepts can be linked in many, many different ways; there are many choices of linking words.



Name (print): ______________________________ **Section:** ______________

Instructions:

- DO NOT OPEN THE EXAM BEFORE YOU READ ALL INSTRUCTIONS AND ARE READY TO BEGIN IT!
- This portion of the Final Exam is to be completed before Thursday, May 16 - 7 pm.
- The enclosed question covers material from the entire course and will count as part of your grade for the final exam grade. You are encouraged to look over your notes from the semester before starting. You should not talk to anyone who has already completed the exam prior to taking it.
- **The enclosed problem is closed notes** – you may not consult your semester notes, the textbook, or any other resources (the web, friends, etc.) unless explicitly allowed by the problem instructions once you have opened the problem and started.
- There is no time limit for this portion of the exam. During the exam, you may step away, eat, sleep, take a walk, or contemplate within any way you wish within the rules set forth in these instructions.
- You may contact Dr. Roberts by email (robermat@uwplatt.edu) if you have questions after starting the problem.

Sign your name below to indicate that you understand these instructions and will abide by them:

____

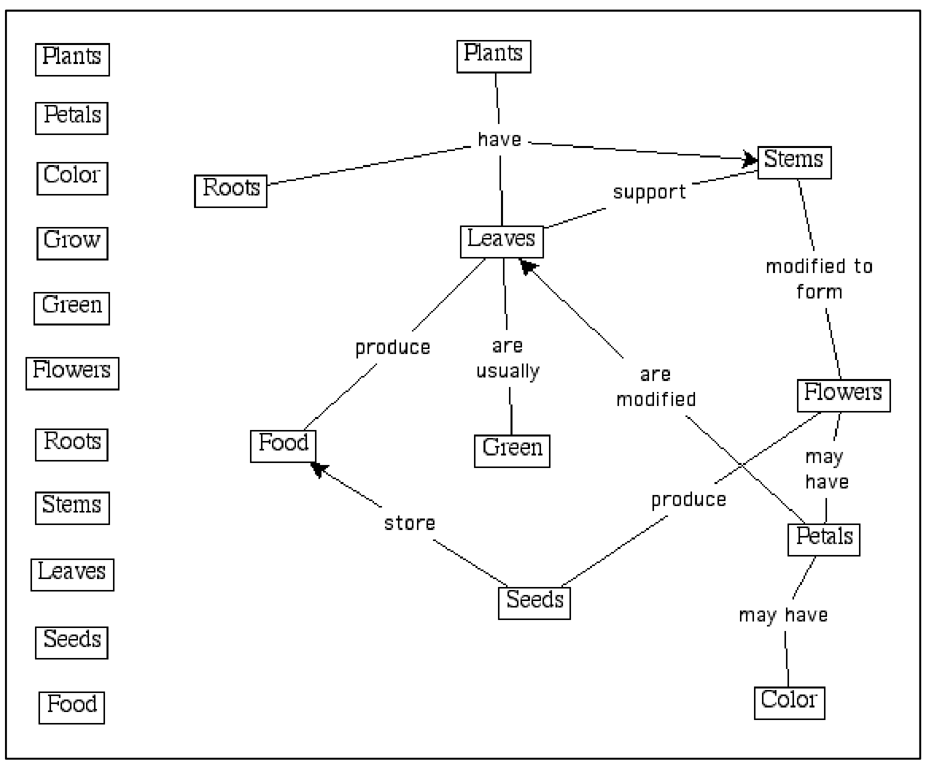
Problem:

Use the bubbl software (https://bubbl.us/) to create a concept map elaborating on the question: "**What is infrastructure**?"

- This question will be graded based on the following criteria (among others):
    - The number of concepts (bubbles) you come up with
    - The variety of concepts you come up with
    - The number of links (lines and arrows) you come up with (linking words are required)
    - The variety of links you come up with
    - The factual correctness of the links you come up with
    - The neatness and legibility of your work (check to make sure that when you print your result, the words are clearly readable, text is not too small, links are clear, bubbles do not overlap and obscure one another, etc).
- You may review the video explaining how to use the bubbl software that is posted on D2L. It is the last item in the content section. Reminder – you should not be reviewing any of the other items posted on D2L as you have already begun the problem by this point.
- When you are done with your map, **print your concept map as a pdf** and submit that pdf file to the dropbox on D2L (Learn@UW). Also, print out a hardcopy of your map which you should staple to this sheet and turn in at the beginning of the final exam on Thursday, May 16, at 7 pm.

Example:

The idea of concept mapping may be best understood with the example to the left (source: https://www.msu.edu/~luckie/ctools/). Consider the following (simple) concept map that answers the question "What is a plant?" To the left of the concept map is a list of concepts, and these have been arranged in the map. Note that there are a very large number of possible concepts that could go in the list of concepts; these concepts can be arranged in any number of ways; the concepts can be linked in many, many different ways; there are many choices of linking words.



Concept Map Scoring Instructions

There are six dimensions to the concept map rubric. Follow the instructions below to determine the "score" for each dimension. Then plot the dimensions on a radar chart. A sample concept map that has been "graded" is provided at the end of this document.

It is imperative that someone with content expertise score the rubrics. It would be very difficult for a non-expert to judge the correctness of links on the concept map.

1. Infrastructure Components – Sum the total number of infrastructure components included on the concept map. The components listed below are certainly not an all-inclusive list.
   a. Transportation Sector
      Components: Streets, rail, non-motorized infrastructure, highways, aviation infrastructure, parking, ports, mass transit, waterways, lighting, signs, signals, markings
   b. Structures Sector
      Components: Bridges, buildings, foundations, towers, retaining walls, tunnels
      Note: schools, hospitals, courthouses, etc. should be counted as buildings even though they hint at government as a part of infrastructure.
   c. Hazardous Waste Sector
      Components: Landfills, transfer/storage facilities, incinerators, contaminated sites
   d. Solid Waste Sector
      Components: Landfills, transfer stations, incinerators, composting, recycling
   e. Stormwater Sector
      Components: Detention ponds, infiltration basins, inlets, gutters, catch basins,
   f. Energy Sector
      Components: Power plants, transmission lines, transformers,
   g. Wastewater Sector
      Components: Waste water treatment plant, conveyance system (e.g., sewer systems)
   h. Parks and Recreations Sector
      Components: City parks and recreation facilities, national parks, state parks
   i. Water Supply Sector
      Components: Reservoirs, conveyance channels and pipelines, treatment, storage
   j. Telecommunications Sector
      Components: Telephone, television, cable, Internet, cell-phone towers, satellites
   k. Flood Control Sector
      Components: Dams, levees
   l. Support of Natural Environment Sector
      Components: Source of natural resources, sink for pollution
2. Sectors – For each infrastructure component mentioned above determine the sector to which the component belongs and sum the total number of sectors represented. Note:
   a. The sector (transportation, structures, etc.) does not need to be specifically mentioned to be counted.

b. Sectors that are specifically mentioned are always counted even if there are no corresponding infrastructure components. (See the "Notes" section below for more guidance.)
c. Do not count the civil engineering sub-disciplines (construction, environmental, geotechnical, structural, transportation) unless

3. CORRECT Technical Links – Sum the total number of links made between technical concepts.
   a. Component to component
   b. Sector to Sector
   c. Sector to component from a different sector (see "Notes")
   d. Engineering concepts to components/sectors
4. Non-technical aspects – Sum the total number of non-technical concepts such as:
   a. Communication
   b. Emergency response
   c. Economic Growth
   d. Economy
   e. Energy
   f. Ethics
   g. Funding
   h. Government
   i. People-serving
   j. Politics
   k. Pollution
   l. Public health
   m. Public safety/Security
   n. Social impacts
   o. Teamwork
5. CORRECT Non-technical links – Sum the total number of links between concepts that do not link two technical concepts
6. Engineering concepts such as:
   a. Assessment (e.g., PASER)
   b. Code of Ethics
   c. Constructability
   d. Decision-making
   e. Design
   f. Environmental Impact
   g. Green Infrastructure
   h. Life cycle costs
   i. Maintenance
   j. Materials (see Figure 1)
   k. Planning
   l. Resilience
   m. Risk management
   n. Safety factors

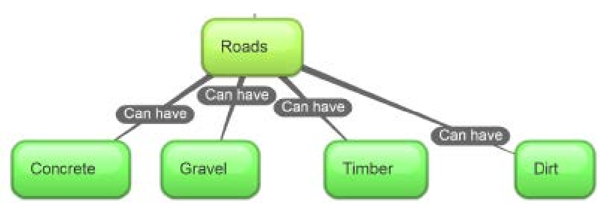


Figure 1 - Engineering materials. Note that in this example the student has identified multiple materials that can be used to construct roads. The four concepts (concrete, gravel, timber, and dirt) together would count as one engineering concept.

Appendix 3: Concept Map Scoring Instructions

o. Sustainability
p. Systems

These six categories become the dimensions for a radar chart.

On the last page is a sample concept map that has been graded using the rubric and the resulting radar chart.

Notes

1. Do not count any concepts without linking words.
2. Do not count civil engineering subdisciplines (e.g., transportation, geotechnical, etc.) as concepts.
3. Links originating from the main concept (e.g., "infrastructure") are not considered in the scoring of the concept map.
4. Links to examples of a concept also not counted (see Figure 2), although links from such examples to other concepts should be counted.

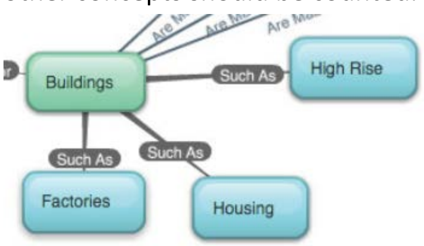


Figure 2 - Specific Examples of infrastructure components

The concept bubbles "High Rise," "Factories," and "Housing" are specific examples of the "Buildings" component of infrastructure and should not be counted. However, if there were unique links from one of these examples to another concept, those links would be counted.

5. If the Infrastructure Sectors (transportation, structures, etc.) are identified on the concept map, then links from sectors to components are counted as "infrastructure components" and are not also counted as technical links (see Figure 3). Also, if the component is listed under the wrong sector (as in Figure 3) the component is still counted along with its corresponding sector.

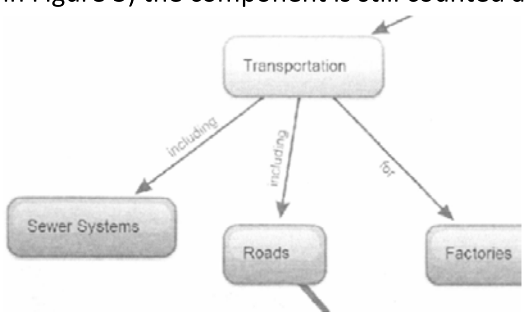


Figure 3 - Infrastructure components listed under an infrastructure sector. "Sewer Systems" and "Factories" are not traditionally considered to be part of the transportation sector, but are still counted as a component along with their corresponding sector (wastewater and structures). "Roads" would be counted as an "infrastructure component" but would not be counted as a technical link.

6. Apart from the exceptions in items 1 - 4, all correct concepts and links should be counted.
7. Each concept should only be counted once, no matter how many times it is mentioned on the concept map.
8. Concept maps that could be used for calibration - #10, #12, #53

Appendix 3: Concept Map Scoring Instructions