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Chemical Engineers' Creating Concept Maps: A Prewriting Activity

Dr. Elif Miskioglu, Bucknell University

Dr. Elif Miskioglu is an early-career engineering education scholar and educator. She holds a B.S. in Chemical Engineering (with Genetics minor) from Iowa State University, and an M.S. and Ph.D. in Chemical Engineering from Ohio State University. Her early Ph.D. work focused on the development of bacterial biosensors capable of screening pesticides for specifically targeting the malaria vector mosquito, Anopheles gambiae. As a result, her diverse background also includes experience in infectious disease and epidemiology, providing crucial exposure to the broader context of engineering problems and their subsequent solutions. These diverse experiences and a growing passion for improving engineering education prompted Dr. Miskioglu to change her career path and become a scholar of engineering education. As an educator, she is committed to challenging her students to uncover new perspectives and dig deeper into the context of the societal problems engineering is intended to solve. As a scholar, she seeks to not only contribute original theoretical research to the field, but work to bridge the theory-to-practice gap in engineering education by serving as an ambassador for empirically driven educational practices.

Chemical Engineer's Creating Concept Maps: A Pre-Writing Activity

This full paper describes the implementation and evaluation of concept maps as a pre-writing activity in chemical engineering. Concept mapping provides a non-linear means for organizing information around a central topic that allows the creator to demonstrate their knowledge of a topic, identify new connections among concepts related to the central topic, and identify areas where they need more information to understand the topic. Chemical engineering students tasked with developing a technical proposal were given a concept mapping assignment as an early pre-writing task. Participants were from two courses, Technical & Professional Communication and Separation Processes, and ranged from sophomore to senior. Concept maps were scored using traditional scoring, a method that computes a numerical concept map score from the number of concepts, number of hierarchies, length of the highest hierarchy, and number of crosslinks (connections across hierarchies). Concept maps were also scored qualitatively by the instructor for structure. For the most part traditional scoring correlated with qualitative analysis (a higher traditional score signaled a more complex map structure) but notable exceptions occurred. These exceptions typically fell into high traditional score/simple structure and were maps that included many concepts but did not synthesize connections between the concepts through crosslinks. Use of concept maps did force students to organize their ideas prior to writing, and did cause many to realize they needed to do further research before writing. Used in concert with other pre-writing activities, they may serve as a valuable tool for engineers in preparing papers and other writing products. From an instructor standpoint, evaluation can be difficult; however, the widespread correlation between traditional scoring and the instructor's qualitative score may suggest that traditional scoring could be leveraged as a mechanism for feedback. The relative simplicity of traditional scoring, and current efforts by others to create automated traditional scoring tools to support concept map use, promote the feasibility of more widespread adoption of concept mapping.

Motivation and Background

Communication is an indisputably important engineering skill. Writing can be a particular challenge, as engineering is often characterized as a discipline of strictly math and science and engineers are prevalently stereotyped as being poor writers. While communication skills are in accreditation criteria and many programs have writing requirements, writing may still be seen as something external to engineering rather than as part of the discipline itself [1].

Communicating or sharing expertise is among the many reasons practicing engineers write. Being able to clearly do so requires a thorough understanding of both the content area and audience. Prewriting, a catch-all term used to describe everything before writing a first draft, is an incredibly important piece of the process of writing that forces the writer to begin organization and synthesis prior to drafting [2-5]. The motivation for this work comes from a decade of experience teaching technical and professional communication to engineering graduate and undergraduate students and the observed resistance to engaging in prewriting. The majority of students encountered prefer to jump straight into writing, seeing prewriting as a cumbersome task that takes up time without seemingly obvious benefit. Reflecting on student resistance to pre-writing activities, such as the popular outlining, raised the question of what other, perhaps less traditional, approaches might be offered to students as prewriting strategies for their professional toolboxes? Recognizing engineers broadly prefer *visual* over *written* modes of information sharing [6], concept mapping arose as a possible option.

Concept maps are a tool that graphically organize knowledge by theme or concept using linking phrases (often verbs) to form a complete thought (proposition) [7-9]. Concept maps have demonstrably improved English as a foreign language university students' argumentative essay writing [10], and graphic organizers, a similar tool, have demonstrated similar effectiveness [11]. While side-by-side comparisons of no prewriting, outlining, and visual clustering (a similar idea to concept mapping) showed that students who engaged in outlining developed better writing artifacts than those who clustered, both prewriting activities showed significant improvement over the control (no prewriting) [12].

This work explores the use of concept maps as a prewriting activity and compares maps produced from a second-year chemical engineering participant population with upper-level students. Maps are compared by employing two separate scoring methods as a means to understand how students in each population approach mapping with little prior experience. In doing so, this work provides a better understanding of concept mapping assignment and evaluation as a basis for further developing lessons and activities to provide students with concept map experience.

Methods

Sample and Recruitment: Participants were recruited from courses taught by the researcher in Spring 2021, Fall 2021, and Spring 2022. The spring course was Technical & Professional Communication, an upper-level elective open to all engineering students. The fall course Separation Processes, is a sophomore-level required course in the chemical engineering curriculum. All students in Separation Processes course were chemical engineers, and all but a four students in Technical & Professional Communication were chemical engineers. In each course students were given a concept mapping assignment as part of their regularly assigned work. Informed Consent was included with the assignment, and students had the option to opt-in to their concept maps being part of the collected data for the study.

Data Collection: Participants were assigned a concept mapping activity as a pre-writing exercise for a larger proposal assignment. Specifics about the prompt for each group are provided in Table 1. In the proposal assignment, students were developing a persuasive argument to convince their target audience to take some desired action (greenlight a project, fund some research, implement a new approach). The goal of the concept map was to provide students with an alternative form for organizing their thoughts and recognizing what gaps remained in their understanding of, research on, or argument for their topic. The assignment included a brief reflection asking the students to share what new connections the map allowed them to see and what "unfinished business" it surfaced. Students did not have previous experience with concept maps, and were given detailed instructions highlighting the steps of concept mapping (creating a list of concepts, arranging the concepts, connecting concepts, labeling the connections with descriptors of the connection) but no other direct training. All participants made two maps, one initial draft early on in the writing process and a second, updated draft later on. Only the final concept map was collected as data.

Table 1. Specific prompts for each group, as well as shared prompts for both groups

Use Case	Prompt
Upper-Level Course	The business model canvas is one approach to organizing a proposal. A concept map offers another way to organize the same information, but with additional opportunities to represent how these pieces are all connected to your core proposal. For this assignment, you'll be generating a concept map of your proposal. With your proposed idea as the starting point, translate (and add to!) the Business Model Canvas you started in class. Once again, we'll be using the Cmap software at cmap.ihmc.us.
Second-year Course	A concept map is a way to organize information that is often used formally or informally by experts or those seeking expertise. It provides a visual representation of how ideas, concepts, or facts are interrelated and supports building the connections that are critical to expertise development. For this assignment, you'll be generating a concept map of your final assignment recommendation, focusing on the argument for the *value* created by the separation process. Use the Final Assignment questions and your proposed idea as the starting point, develop a concept map using the Cmap software at cmap.ihmc.us, or complete a concept map by PowerPoint or hand. Just make sure it's neat!
Reflection (included for both groups)	Answer the following prompts in a 200-300 word narrative. • Are there any connections that have emerged that you were previously unaware of? • What questions come to light regarding your proposal? • What connections are strong? Which ones appear weak? • What unfinished business do you have in formulating your proposal idea/value proposition?
Important notes (included for both groups)	Considerations for your concept map: • Linking lines should be labeled, and those labels should be verbs. One label can branch out to many boxes, look for and clean up that kind of repetition if it exists! • Break apart compound phrases into separate ideas • Look for crosslinks! A lack of crosslinks should be a red flag

Each participant generated their own unique participant ID based on a combination of their middle initial, number of birth month, and first two letters of birth city. Concept maps were generated using CMap Tools. In rare cases participants were unable to access CMap Tools and generated their concept maps through an alternative program such as Microsoft PowerPoint. Concept Maps were submitted through the course Learning Management System (LMS). Participants were instructed to only use their participant ID on the concept map and in the file name to create immediate de-identification. Upon download from the LMS no identifiable information remained and maps with participant IDs for which consent was not given were deleted.

Data Analysis: Data analysis was done using and comparing two approaches to scoring concept maps: 1) traditional scoring, a quantitative approach [7, 8], and 2) structural holistic scoring, a qualitative approach. In traditional scoring, the number of concepts, length of the highest hierarchy, and number of crosslinks are used to calculate a numerical concept map score as follows:

$$\textit{Number of Concepts} * 1 + \textit{Length of Highest Hierarchy} * 5 + \textit{Number of Cross Links} * 10 = \textit{Total Score}$$

In structural holistic scoring, the structure of the map is identified as belonging to one of five categories: linear, circular, hub-and-spoke, tree, or network. Here the network is arguably the most complex map as it represents a map that has crosslinks between hierarchies.

After scoring was complete, comparisons were made between the second-year and upper-level students.

Findings

In general, upper-level students produced more complex concept maps as evidenced by their higher mean of traditional scores and greater proportion of networks. Comparing scores and structures for individual students, the lowest scoring maps in the second-year population were more likely to be trees in structure. These three findings are described in further detail below.

Finding 1: Upper-level students have a wider range and higher mean of scores.

The highest two scores for the upper-level students and the highest score for the second-year students were all outliers (Figure 1). Among the upper-level population the differentiating feature of these concept maps were their number of crosslinks. These concept maps had > 10 crosslinks, compared to the population average of 2.8 crosslinks (Table 2). For the second-year population, the outlier concept map has the longest highest hierarchy, with a hierarchy of 11 when the population average is 4.8.

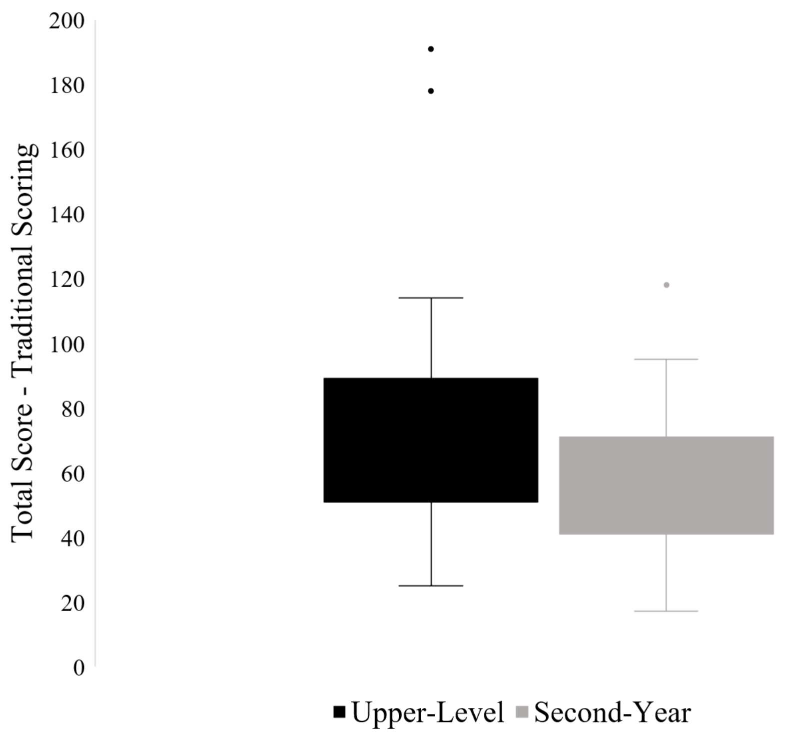

Figure 1. Quantitative score ranges for upper-level elective students and second-year students.

Table 2. Average value for each component of traditional score for upper-level versus second-year students.

	Upper-Level (n = 22)	Second-Year (n = 16)
Number of Concepts	25.6	19.2
Highest Hierarchy	4.4	4.8
Number of Crosslinks	2.8	1.5

Finding 2: Upper-level students are more likely to produce concept maps with network structures.

Trees (Figure 2) and networks (Figure 3) were the only two structures observed in the sample. Networks were the dominant structure among concept maps in both groups (Table 3). However, a greater proportion of concept maps produced by upper-level students (82%) were networks compared to second-year students (63%).

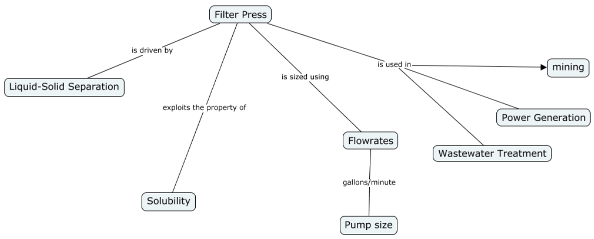

Figure 2. Example of concept map with tree structure.

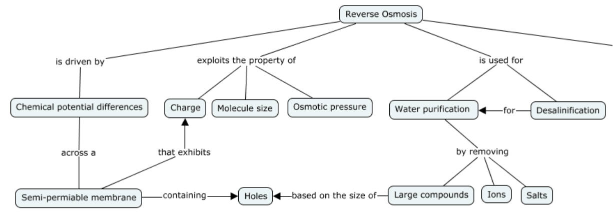

Figure 3. Example of concept map with network structure.

Table 3. Percent of each structure, trees and networks, among upper-level versus second-year students.

	Upper-Level (n = 22)	Second-year (n = 16)
Number of Trees (% of concept maps)	4 (18%)	6 (38%)
Number of Networks (% of concept maps)	18 (82%)	10 (63%)

Finding 3: Among second-year students, the lowest scoring maps were most likely to be of tree structure.

In the second-year population, the lower quartile scores were those below 44. Of the five concept maps in this lower quartile, four maps had tree structures. There was also one tree structure in the each of the second and third quartiles. In the upper-level students the four concept maps with tree structures were all maps in the lower half of scores. Two were in the lower quartile and two were in the second quartile. Neither population had concept maps with trees in the highest quartile of score.

Discussion and Implications for Future Use

The weight placed on the number of cross links in traditional scoring (*10) and the role of cross links in defining the network structure of a concept map make the observed relationships between high traditional score and network structures unsurprising. Crosslinks represent connections between what may appear to students as disparate hierarchies at first glance, and subsequently require a greater level of expertise. The ties between expertise and experience [13-18] may further explain why the upper-level students had a higher proportion of networks and a higher traditional score on average. While few members of either population had any previous experience with concept maps, the upper-level students presumably had greater educational experience and an advantage in domain expertise on their topic. This would support their ability to better identify crosslinks between hierarchies. Additionally, while the concept maps in both contexts were graded on completion only and a small portion of the overall coursework, the upper-class students' concept maps supported a higher-stakes and larger assignment compared to the second-year population. It is possible that the nature of the assignment supported by the concept map influenced student motivation, which is observed in scores.

Regardless of differences between groups, it was observed that concept mapping did not come naturally to most students in either group. Breaking propositions into central topics and linking words or phrases was particularly difficult for the participants. This was consistent between draft and final concept maps, suggesting that an additional concept map training exercise may be valuable in future adaptations of this activity and advised for others seeking to implement concept mapping into their course activities. To ensure high quality concept maps, it may also make sense to give the students some guidelines for how many concepts, hierarchies, or crosslinks a well thought out map might have. While this guidance could cause some students to list unrelated concepts or make random crosslinks to reach the minimum, the hope is it will allow them to self-evaluate and push themselves to develop a higher quality map. Directing students to create a network style map explicitly may encourage them to think more deeply to formulate assignments.

This paper described the use of concept maps as a prewriting activity as a resource for others who may be interested in using this approach. The use of concept maps as a prewriting activity offers a variation on the traditional outline that better embraces the nonlinearity of topics. Allowing the writer to map the domain in a manner more authentically representative of the complexity may then support the writer in crucial decisions about scope and organization.

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