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Benefits of Statics Concept Mapping in Career Cognition

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Benefits of Concept Mapping in Statics

Abstract

The purpose of this research was to develop a classroom project module that supported students in developing conceptual understanding of topics in statics, and building awareness of career value creation in engineering. The module developed includes a sequence of concept mapping activities that students complete that includes both technical topics and entrepreneurial mindset topics. The concept mapping activities were collected from students and scored using traditional and holistic approaches. The students completed a survey at the end of the concept mapping activities to provide insights about their experiences. The concept mapping for technical topics was found to be a useful formative assessment tool for students to connect concepts in the course. The value creation career results were compared with prior studies of engineering students who developed concept maps based on entrepreneurial mindset, and found to be very similar. The results indicate that this type of simple concept mapping activity can have benefits for students early in their engineering coursework to reflect on mindset and technical knowledge.

Introduction

This paper describes a classroom module designed to increase engineering student skills in both statics and value creation career formation in the context of building an entrepreneurial mindset. For this work, we define entrepreneurial mindset to be consistent with the Engineering Unleashed community, "*An entrepreneurial mindset (EM) influences the way you think about the world and act upon what you see. It is a collection of mental habits that empower you to question, adapt, and make positive change, leading you to: Recognize and identify opportunities; Focus on their impact; Create value in any context.*" [1]

The module developed had several objectives:

1. Does the development of concept maps help engineering students connect technical topics?
2. Does the development of entrepreneurial mindset concept maps help students connect engineering value creation with their own goals?

The research goal of the project was to determine if a structured module in an engineering course could help students demonstrate knowledge of course topics, while also encouraging students to think about long-term career connections, one of the key ideas of EM. Concept mapping has been used infrequently in Statics courses, but offers a useful formative assessment tool.

This module is also part of a larger effort at the University of Washington Tacoma to expose students and faculty to the entrepreneurial mindset in engineering. One facet of the entrepreneurial mindset (EM) as defined by the Kern Entrepreneurial Engineering Network (KEEN) is creating value, the idea that engineers may create value to society, economic value, or other types of value [2]. This idea aligns well with the ABET SEO 4: an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgments, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts.

Background

Engineering faculty have been working to incorporate entrepreneurial mindset in curriculum for many years. Recent efforts in mechanical engineering programs have focused on modules embedded in engineering classrooms that support mindset development in students [3]–[5].

Many prior authors have published in the field of concept mapping in engineering. One of the most relevant studies by Martine et al. [6] and Ferguson et al. [7] discuss methodology for scoring concept maps that is relevant for our work. Cornwell provides an overview of the way concept mapping may support the mechanical engineering curriculum broadly [8]. A summary of prior work is shown in Table 1.

Table 1. *Summary of concept mapping methods from the literature.*

Author	Year	Student Level	Course	Methods
Fang [11]	2012	Second year	Dynamics	Students construct maps for technical topics in the course
Moore et al. [12], [13]	2012	First/ second year	Statics	Use of concept maps to organize info in statics class; starting from bottom up
Roberts et al. [14]	2014	Third year	Intro to Infrastructure	Goal of course is to understand civil engineering using interconnected systems

Barrella et al. [15]	2016	First year	Intro to engineering	Concept maps as assessment tool for course learning objectives
Mendez and Lofton [16]	2021	Third year	Fluid Mechanics	Instructor maps and student maps compared at two institutions
This Study	**2022**	**Concept Mapping**	**Statics and EM**	**Analysis of student generated maps for technical and EM concepts.**

Bodnar et al. has published efforts to create a comprehensive concept map for students tied to concepts of entrepreneurial mindset [9]. Jackson et al. did semi-structured interviews with students to learn more about how they think about entrepreneurial mindset [10].

Only one prior research team focused on the use of concept mapping in a statics classroom, but the concept maps highlighted were developed by faculty as an instructional tool [12], [13]. In contrast, our focus was on allowing students to develop their own concept maps to demonstrate knowledge of the topics. The prior work did not tackle value creation connections or the entrepreneurial mindset in the class.

Concept Mapping Module Design

The module was designed to be added to an existing class structure. Students were first exposed to concept mapping in a technical aspect of the course. Prior to the concept mapping activity, students were shown an example of a concept map that focused on french fries so they understood the general structure of concept mapping. The format of the worksheet is shown in Appendix A.

As part of the traditional statics curriculum, students were exposed to various topics throughout the term, including force vectors, equilibrium, moments, structures and friction. After students acquired sufficient knowledge in these areas, they were provided with word banks in four main areas: equilibrium, forces and moments, structures and friction. These are traditionally regarded as the fundamental knowledge blocks within statics curricula. The prompts were as follows:

For this assignment, you will complete a concept mapping exercise to help you organize your knowledge of statics. Using the word banks below, create a concept map for each main topic. Each box is a subtopic in statics, and each line is a way the subtopics are connected. The lines *are labeled with ways in which the subtopics connect. Typical line labels include subset, application, and methods.*

Students were given the freedom to add related subtopics that were not included in the word banks, but were instructed to keep the main topic intact.

Students were also trained in a software tool to improve the quality of the concept mapping. Prior to the first assignment, the students were briefly trained on how to use a concept mapping software called "cmap Tools". The software is free and available as both a tablet application and desktop application [17]. Students found it relatively easy to use the tool, and the quality of the mapping improved significantly (when compared to an unpublished pilot study) since students used connecting words.

Near the end of the term, students were then asked to create a concept map exploring engineering careers. Students were asked "*How do engineers create value?*" as an open ended start for a concept map. Because students were already familiar with concept mapping for a technical topic, they were able to use the software tool easily for the second assignment, and focus on career value creation connections.

Assessment Methods

The research team used two methods to assess the students, a survey and analysis of the student concept maps. The survey was approved by IRB prior to the class module, and asked students to opt in to the research project. The student survey included the following questions:

- Gender and identity demographics (selected choice)
- Do you have any prior experience or knowledge of entrepreneurial mindset or entrepreneurship? (selected choice)
- Was this prior experience or knowledge of entrepreneurial mindset or entrepreneurship from a specific experience? (selected choice)
- How many courses have you completed where entrepreneurship concepts were discussed? (open text)
- Have you previously had any experience with creating a concept map? (selected choice)

The concept maps were scored by two trained experts using two different methods for assessing concept maps. The scoring was independent of the student coursework grade - simply a complete/incomplete - and was done after the course had ended. The two scoring experts reviewed their results and discussed and adjusted when necessary. Neither of the scoring experts included the instructor for the course to reduce bias.

The first scoring method was traditional. The traditional scoring method for concept maps is based on work by prior researchers [6] . The traditional method requires counting of specific elements of the concept maps.

- Number of Concepts (NC) is a simple count of the number of concepts in each map. This may help quantify the breadth of student knowledge.
- Highest Level of Hierarchy (HH) is calculated based on the number of concepts in a single chain in the map.
- Number of Cross-Links (NCL) is calculated based on the number of concepts connected between branches.

One advantage of traditional scoring is that it does not require knowledge of the subject or evaluate for correctness of the map. To address these additional features of the concept maps, a second method of holistic scoring was used.

Holistic scoring was also developed by prior authors. This method evaluates each concept map based on three areas that are qualitative. Each area is assessed from one to three (highest) using a rubric adapted from Besterfield-Sacre et al. [18].

- Comprehensiveness. For the highest score (3), the map completely defines the subject area. The content is lacking no more than one extension area.
- Organization. For the highest score (3), the map is well organized with concept integration and the use of feedback loops. The map demonstrates sophisticated branch structure and connectivity.
- Correctness. For the highest score (3), the map integrates maps properly and reflects an accurate understanding of subject matter.

The holistic scoring required more judgment calls by the scoring experts, but served as a useful way to characterize the student concept maps.

Prior work by Martine et al. [6] found that the scoring for holistic and traditional methods is often well aligned as long as the map complexity was relatively low. Differences between the two methods increase as the map complexity increases.

Concept Mapping Module Results

In the first (pilot) offering of the module, a small number of student concept maps were collected. The students did not use the cmap software tool and created concept maps that were difficult to analyze. The results from the pilot offering are not included in this paper. In the second offering of the project (the focus of this paper), the software tool helped the students structure the maps in a way that allowed more structured analysis.

The results for the concept mapping project in the were very good for a preliminary module. 11 students, 91.6% of the total class, completed the survey and permitted analysis of the concept maps during the second year of the project. While the sample size is relatively small, the student results merit further research on this topic.

The instructor observed that the module was most useful for helping students understand how the fundamental topics within a technical course like statics connected. This serves as a building block for students to not only focus on the technical skills but on the broader necessity to find opportunities and challenges and develop creative solutions.

Student Survey Results

The student survey was completed by 11 students, representing about 91.6% of the possible respondents. 36% of the students responding were female and 64% were male.

Most of the students reported that they did not have prior knowledge of entrepreneurial mindset (91%), and only a few reported prior experience with concept maps (27%). These results confirm that the student had little prior exposure to entrepreneurial mindset topics, which we expected from students taking the first program course (statics).

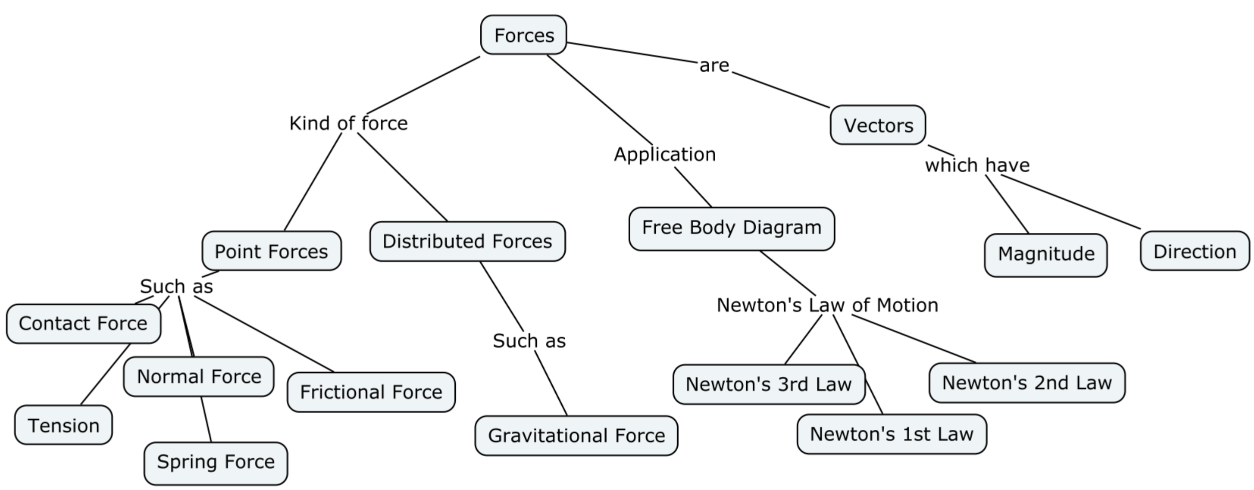

Figure 1. Example of a student generated concept map connecting key ideas in a statics course.

Student Map Results

The student concept maps for statics materials were well constructed and clearly helped students connect different concepts in the course. An example of a student concept map for the technical work is shown in Figure 1. In this example, the student clearly connected forces to free body diagrams and important concepts like vectors. This classroom module was very successful in helping students think about technical materials, and was relatively easy to implement in a course. The concept map allowed students to demonstrate knowledge they had gained in the course, while also making key connections more concrete.

The concept maps focused on EM were also a thoughtful exploration for the students. The maps reviewed indicated most of the students had considered value creation in a broad context. An example of a student concept map from this part of the project is shown in Figure 2.

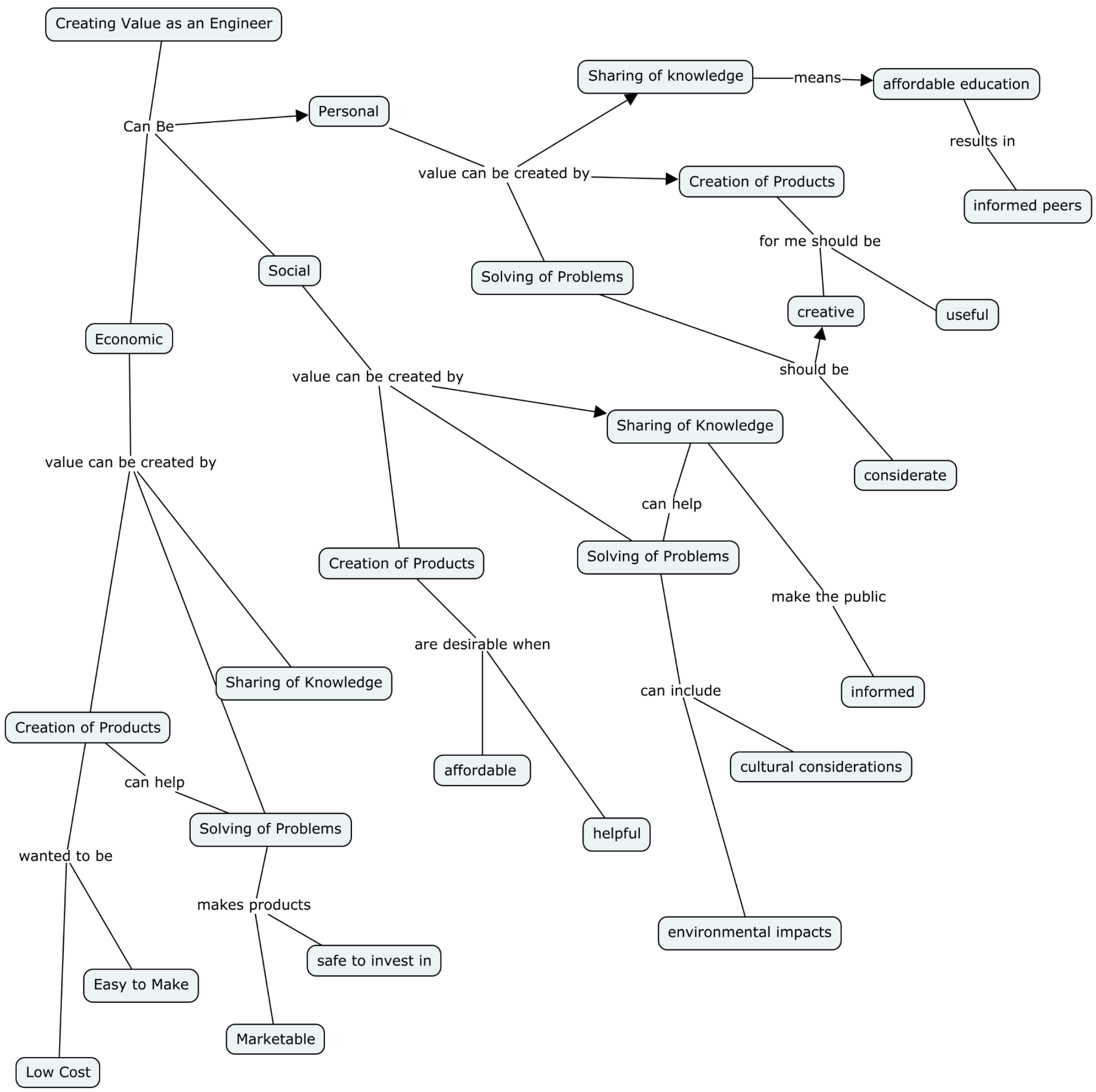

Figure 2. Example of a student generated concept map focused on the prompt, “How do engineers create value?”

Table 2 and Table 3 provide an overview of the scoring summary for each type of concept map based on the scoring method. The student concept maps were analyzed by two independent trained researchers. To understand how our student maps compared with a larger sample set we compared them with published results from Martine et al. [6]. This group was a good comparison, because they had recruited students to attend an innovation event, who also may have had little prior experience with EM. The Martine et al. study compared engineering students and business students, but we have simply compared with the published results for engineering students. The prompt used for the concept maps in the Martine et al. study was also focused on the entrepreneurial mindset.

Table 2. Summary of traditional concept map scoring for students in this study, compared with prior results from [6]. The number of students that completed the concept maps for EM and statics were slightly different.

Rubric Category	Mean for Statics Maps in this Study (n=11)	Mean for EM Maps in this study (n=9)	Mean for Engineers at Rowan University (n=19)
Concepts (NC)	15.2	17	17.16
Hierarchy (HH)	3.00	2.89	2.68
Cross-Links (NCL)	1.73	1.00	2.32

For the traditional scoring method, our students used slightly fewer concepts for statics than EM, but were fairly consistent in the hierarchy structures. For statics maps, they had a higher number of cross-links than for EM, possibly indicating they see more ways that concepts connect in the statics topics. We expect this number of cross-links to increase as the students are exposed to knowledge about EM in the same way they are taught about statics topics. It may also be due in part to the differences in the prompts, since the students had a word bank for statics and they did not for EM.

The traditional scoring was very similar for the Rowan students to our own for all values except the number of cross-links. This is a helpful result since the students in both studies were exploring EM ideas without prior training. We would expect the number of concepts and cross-links to increase as students gain insights about EM.

The results show that our students' maps for statics concepts were slightly higher in the holistic scoring than the same cohort of students' performance on the EM mapping for organization and correctness, and very similar for comprehensiveness. This supports the idea that formally training and discussion of EM and career objectives may be helpful for students to make sense of how their engineering careers may create value. While no formal EM training module was used in this statics course, our results encourage us to increase this type of conversation in the future.

Table 3. Summary of EM concept map holistic scoring for students in this study, compared with prior results from [6].

Rubric Category	Mean for Statics Maps in this Study (n=11)	Mean for EM Maps in this study (n=9)	Engineers at Rowan University (n=19)
Comprehensiveness	2.10	2.17	1.79
Organization	2.27	2.00	1.89
Correctness	2.77	2.44	2.79
Total	7.14	6.61	6.47

For the holistic scoring EM maps, our student results were slightly higher than the Rowan students for all categories except correctness. Since both studies had a small number of students the variance seems reasonable, and could be explored further with larger sample efforts in the future.

Conclusions

A new project was developed for engineering students to help them develop connections between career and classwork using concept mapping. The module was incorporated into an existing Statics course taken by mechanical engineering and civil engineering students in the second year of the program. The course module was observed by the instructor to be helpful for students to think about connections in careers and technical topics.

Analysis of student work indicated a significant improvement in the module (compared to an unpublished pilot), when students were provided with additional training and used a software tool to create more robust concept maps. The student career mapping reflected a broad breadth and depth of connections between awareness of engineering and value creation. The scoring of the maps were compared to prior studies with concept maps focused on entrepreneurial mindset and found to be similar.

For the first research question, “Does the development of concept maps help engineering students connect technical topics?” we found that the student maps were a helpful formative tool for students to explore and connect knowledge in a statics course. The concept maps they generated were of high quality and had high correctness scores. The mapping process allowed students to demonstrate their knowledge in a concrete way, and to think about new connections.

For the second research question, “Does the development of entrepreneurial mindset concept maps help students connect engineering value creation with their own goals?” we found the activity and prompt were a good introduction to connecting ideas about career value creation and entrepreneurial mindset. Although most students had no prior exposure to the entrepreneurial mindset, the act of creating a concept map and brainstorming around engineering value creation created high quality maps. The results were similar to those of engineering students in another study that did not have prior exposure to EM. We plan to continue work on this research question over time, as we have prepared a longitudinal study to continue tracking how the student EM maps change over the course of their engineering degrees.

Future work will include adjusting this type of concept mapping module in other classes in the curriculum. This type of connection to career value creation early in the program may have benefits for student retention, and directly aligns with ABET outcome 4.

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References

[1] “Entrepreneurial Mindset | Engineering Unleashed.” https://engineeringunleashed.com/mindset (accessed Mar. 13, 2022).
[2] D. Rae and D. E. Melton, “Developing an entrepreneurial mindset in US engineering education: an international view of the KEEN project,” *J. Eng. Entrep.*, vol. 7, no. 3, Art. no. 3, Feb. 2017, Accessed: Feb. 03, 2022. [Online]. Available: http://www.jeenonline.org/Jeen_Vol7_Num3.html
[3] J. Farina, H. Dillon, R. D. Levison, and N. Ralston, “Increasing Student Curiosity with Cooling Systems,” presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Feb. 03, 2022. [Online]. Available: https://peer.asee.org/increasing-student-curiosity-with-cooling-systems
[4] H. E. Dillon, J. M. Welch, N. Ralston, and R. D. Levison, “Students Taking Action on Engineering Ethics,” presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Feb. 03, 2022. [Online]. Available: https://peer.asee.org/students-taking-action-on-engineering-ethics
[5] K. Bieryla, N. A. Schulz, R. D. Levison, and H. Dillon, “Play-Doh and Pendulums: Making Mass Moment of Inertia Fun,” presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Feb. 03, 2022. [Online]. Available: https://peer.asee.org/play-doh-and-pendulums-making-mass-moment-of-inertia-fun
[6] M. M. Martine, L. X. Mahoney, C. M. Sunbury, J. A. Schneider, C. Hixson, and C. A. Bodnar, “Concept Maps as an Assessment Tool for Evaluating Students’ Perception of Entrepreneurial

Mind-set," presented at the 2019 ASEE Annual Conference & Exposition, Jun. 2019. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/concept-maps-as-an-assessment-tool-for-evaluating-students-perception-of-entrepreneurial-mind-set
[7] S. M. Ferguson, R. W. Foley, J. K. Eshirow, and C. C. Pollack, "Refining Concept Maps as Method to Assess Learning Outcomes Among Engineering Students," presented at the 2018 ASEE Annual Conference & Exposition, Jun. 2018. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/refining-concept-maps-as-method-to-assess-learning-outcomes-among-engineering-students
[8] P. J. Cornwell, "Concept Maps In The Mechanical Engineering Curriculum," Jun. 1996, p. 1.118.1-1.118.7. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/concept-maps-in-the-mechanical-engineering-curriculum
[9] C. A. Bodnar, S. Jadeja, and E. Barrella, "Creating a Master 'Entrepreneurial Mindset' Concept Map," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/creating-a-master-entrepreneurial-mindset-concept-map
[10] A. M. Jackson, S. Resnick, R. Hansson, and C. A. Bodnar, "Student Perceptions of an Entrepreneurial Mindset and Its Relevance to Engineering Careers," presented at the 2021 ASEE Virtual Annual Conference Content Access, Jul. 2021. Accessed: Jan. 26, 2022. [Online]. Available: https://peer.asee.org/student-perceptions-of-an-entrepreneurial-mindset-and-its-relevance-to-engineering-careers
[11] N. Fang, "Enhancing Students' Understanding of Dynamics Concepts Through a New Concept Mapping Approach: Tree of Dynamics," Jun. 2012, p. 25.574.1-25.574.13. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/enhancing-students-understanding-of-dynamics-concepts-through-a-new-concept-mapping-approach-tree-of-dynamics
[12] J. P. Moore, R. S. Pierce, and C. B. Williams, "Towards an 'Adaptive Concept Map': Creating an Expert-Generated Concept Map of an Engineering Statics Curriculum," Jun. 2012, p. 25.1365.1-25.1365.13. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/towards-an-adaptive-concept-map-creating-an-expert-generated-concept-map-of-an-engineering-statics-curriculum
[13] J. P. Moore, C. B. Williams, C. North, and A. Johri, "Promoting Conceptual Understanding in Engineering Statics Through the Use of Adaptive Concept Maps," Jun. 2013, p. 23.998.1-23.998.13. Accessed: Jan. 26, 2022. [Online]. Available: https://peer.asee.org/promoting-conceptual-understanding-in-engineering-statics-through-the-use-of-adaptive-concept-maps
[14] M. W. Roberts, C. Haden, M. K. Thompson, and P. J. Parker, "Assessment of Systems Learning in an Undergraduate Civil Engineering Course using Concept Maps," Jun. 2014, p. 24.216.1-24.216.18. Accessed: Jan. 26, 2022. [Online]. Available: https://peer.asee.org/assessment-of-systems-learning-in-an-undergraduate-civil-engineering-course-using-concept-maps
[15] E. Barrella, J. J. Henriques, and K. G. Gipson, "Using Concept Maps as a Tool for Assessment and Continuous Improvement of a First-Year Course," presented at the 2016 ASEE Annual Conference & Exposition, Jun. 2016. Accessed: Jan. 26, 2022. [Online]. Available: https://peer.asee.org/using-concept-maps-as-a-tool-for-assessment-and-continuous-improvement-of-a-first-year-course
[16] J. Mendez and J. Lofton, "Two Approaches to Concept Maps in Undergraduate Fluid Mechanics," presented at the 2020 ASEE Virtual Annual Conference Content Access, Jun. 2020. Accessed: Jan. 25, 2022. [Online]. Available: https://peer.asee.org/two-approaches-to-concept-maps-in-undergraduate-fluid-mechanics
[17] "Cmap | CmapTools." https://cmap.ihmc.us/ (accessed Feb. 03, 2022).

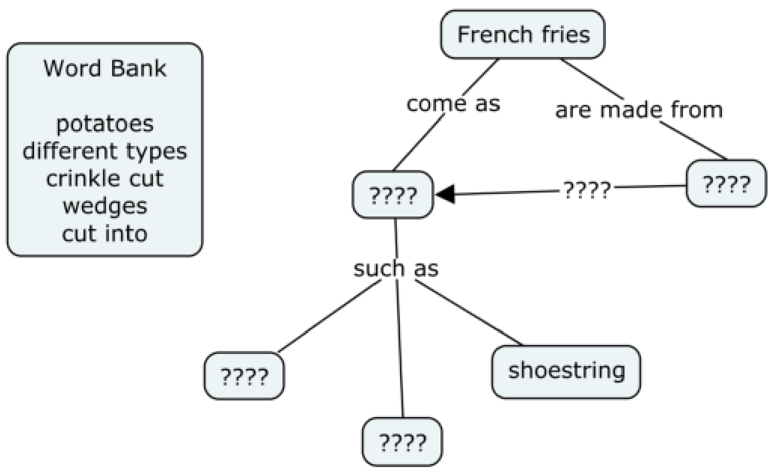
[18] M. Besterfield-Sacre, J. Gerchak, M. R. Lyons, L. J. Shuman, and H. Wolfe, “Scoring Concept Maps: An Integrated Rubric for Assessing Engineering Education,” *J. Eng. Educ.*, vol. 93, no. 2, pp. 105–115, 2004, doi: 10.1002/j.2168-9830.2004.tb00795.x.

Appendix A

Concept Mapping Activity

Objective: *Organize your knowledge of statics using a concept map.*

1. Consider the example concept map for the topic "french fries" below. A concept map is an organizational tool for communicating your knowledge about a particular topic. The structure of a concept map mimics the way neuroscientists think that your brain organizes and stores information, which makes them good learning tools. Take a minute to put the words in the word bank into the blanks in the concept map.



"Picture your brain forming new connections as you meet the challenge and learn. Keep on going."
— Carol Dweck, Mindset: The New Psychology of Success

2. For this assignment, you will complete a concept mapping exercise to help you organize your knowledge of statics. Each box is a topic in statics, and each line is a way the topics are connected. The lines are labeled with ways in which the topics connect. Typical line labels include subset, application, and methods.

Equilibrium

- Forces
- Bodies
- Moments
- Free-body diagrams
- Newton's first law
- Newton's second law
- Newton's third law
- Equilibrium analysis
- Static equilibrium

Structures

- Two Force Members
- Equilibrium analysis for a concurrent force system
- Trusses
- Frames and Machines
- Method of Joints
- Method of Sections
- Equilibrium analysis for an extended body system
- Analysis of Frames and Machines
- Newton's Third Law

Forces and Moments

- Forces
- Moments
- Point Forces
- Distributed Forces
- Statically equivalent Systems
- Couples
- Centroids
- Equivalent Point load
- Resolution of a Force into a Force and Couple
- Equivalent Force Couple System

Friction

- Forces
- Dry Friction
- Couples
- Slipping vs. Tipping
- Wedges
- Bearing Friction
- Disc Friction
- Belt Friction
- Power Screws