Concept Mapping the Entrepreneurial Mindset in a First-Year Engineering Design Course: How Students' Perceptions Shift

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Abstract

This complete evidence-based practice paper looks at a concept mapping activity that was used in a first-year engineering design course. Students created concept maps of the Entrepreneurial Mindset before their design project started and then they were asked to iterate on the map after they completed their design project. This study examines the concept maps and uses an automated scoring tool to complete traditional and categorical scoring. The results show that the complexity of the maps did increase significantly to the final versions and that students included a wide range of topics related to the Entrepreneurial Mindset, spanning all six predefined categories.

Introduction

This complete evidence-based practice paper focuses on a concept mapping assignment in a first-year engineering classroom in Spring 2023. Students were asked to create a concept map on the *Entrepreneurial Mindset* (EM), a term used by engineering faculty in the Kern Entrepreneurial Engineering Network (KEEN) [1] to describe three key concepts: curiosity, connections, and creating value. The students in this course were asked to complete this concept mapping task at the beginning of a semester-long design project and then to expand on it at the conclusion of the project.

Engineering students who develop an Entrepreneurial Mindset are taught to focus on creating personal, societal, and economic value in any job or task they encounter [1], to connect ideas and material from a variety of sources, and to be curious about the world around them. EM has been hypothesized to increase student interest in engineering [2], and the development of the mindset has been shown to help engineers recognize opportunities, evaluate markets, and learn from mistakes to create value for themselves, for their employers, and for society [3]. In this study, students develop a concept map for EM based on what they have learned about the mindset throughout a design project course.

Concept mapping is an instructional tool that is particularly useful for its ability to assess conceptual understanding and connections within complex topics such as EM [4, 5]. It also provides students with an opportunity to reflect and synthesize the connections between big ideas, so it can be useful as a metacognition activity. Concept maps have been used successfully to help students recognize connections between topics in complex courses [5]. Fostering the ability to make these types of connections is a key component in the Entrepreneurial Mindset. The motivation for this work is to study how student perceptions of EM change over the course of a design project using concept maps as an assessment tool.

Background

Entrepreneurial Mindset

The Kern Entrepreneurial Engineering Network (KEEN) is a leader in defining and distributing concepts and course content related to EM in engineering. KEEN is a collaborative network of academic institutions and professors with the shared mission of cultivating the core principles of the EM in their students [2]. This organization guides the network's activity related to curricular development, faculty workshops, and student engagement, and has defined the 3C's of EM to unify their model and educational materials. These 3C's are curiosity, connections, and creating value.

Integrating entrepreneurship concepts into engineering courses has become increasingly common in higher education [6]. A 2015 survey of ASEE members representing 100 institutions indicated that faculty and administrators strongly agree that engineering students should have access to innovation and entrepreneurship education [7]. This increased focus on embedding entrepreneurship in engineering coursework may also stem from engineers' desire to create customer-driven solutions [8]. In addition to this, contrary to common notions that entrepreneurs are born with the skills and mindset they need [9], research has also shown that training and education can produce entrepreneurs [10]. Concept maps have been used by Bodnar et al. [11] to assess student development of an EM holistically and have been used as a direct assessment to measure students' ability to make connections in the context of EM [12].

Concept Maps

Concept mapping, first applied to science education by Novak [5], seeks to capture knowledge in the way it is structured within the brain. An enduring and popular description of memory storage is semantic memory theory which posits that stored and understood concepts are directly linked to one another in a "knowledge network" [13]. The exact structure of these networks is disputed [14,15], but a central importance of concept connectedness is evident. Many traditional knowledge assessment techniques such as multiple-choice assessments fail to capture this more intricate system of connection, so many alternative methods have been proposed [16]. Concept mapping, therefore, is laid out such that a central topic and its dependent concepts are hierarchically connected in a network in order to capture knowledge as it is stored [17].

Concept mapping in education typically entails assigning the creation of a concept map (a sample concept map from this study's dataset shown in Fig. 1) from a topic of importance and subsequent assessment of the map's contents by an instructor or expert, though there are many formats in which they are presented [5,16,17,18,19,20]. Adequate assessment of concept map contents is an ongoing area of study that is beyond the scope of this paper; however, the three prominent scoring methods—traditional, categorical, and holistic—can be broadly described as attempting to capture the complexity of a concept map through assessment of its structure and/or content [17]. Scoring methods typically come with tradeoffs between objectivity, time consumption, and nuance. Of particular importance here are the traditional and categorical methods which can be described as objective methods (i.e. do not include subjective correctness components).

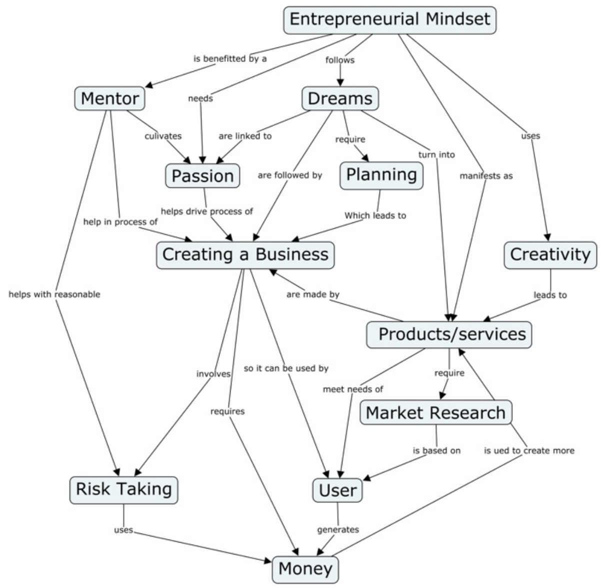

Figure 1: Sample Concept Map. Here an example concept map from the dataset with the central topic “Entrepreneurial Mindset”

The traditional scoring method is designed for simplicity. The most prominent variation of this method was developed by Novak and Gowin [21], seen in Eq. 1. This method breaks the structure of a map into 3 sub-scores that assess the knowledge breadth, depth, and connectedness of a concept map, respectively, and has been shown to be highly successful in assessing high-level understanding [22].

$$Score = NC + 5 * HH + 10 * NCL \tag{1}$$

NC is the number of concepts in the map, those encircled and connected to the network excluding the central topic. *HH* is the highest hierarchy, or number of concepts in the longest continuous direct path from the central topic to a terminating concept which cannot follow along a cross-link or feedback loop. *NCL* is the number of cross-links—instances in which concepts from different branches are linked together.

The categorical scoring method further emphasizes the importance of connectivity, particularly across disparate concept areas within a central topic. Originally developed by Segalas et al. [23] to assess sustainability concept maps, categorical has been successfully expanded to other topics. Of particular interest with this method is its ability to assess the complexity of a concept map in its interdisciplinary connectivity, shown in its formula, in Eq. 2.

$$Complexity = NC * \frac{NIL}{NCAT} \tag{2}$$

NC again is the number of concepts in the map, which excludes the central topic and any linking words. *NIL* is the number of interlinks present in the map—where an interlink is a connection between concepts of different categories. *NCAT* is the number of categories present in the map. Categories for this method are developed either from established principles of the central topic or emergently by an expert or instructor as datasets are assessed. Concepts within each individual map are then binned into these categories for computing of the *NIL* and *NCAT* metrics.

Course Context

The course that the concept map assignment was used in was the second course in a two-course first-year engineering sequence at The Ohio State University. The course focuses on a design and research project. The design project that students were assigned in the course was a semester long where students were tasked in identifying an opportunity and defining a problem within the themes of medical nanotechnology or sustainability. Students worked in teams of four to identify opportunities of interest to them, conduct significant research including scientific journal articles, and then propose a solution to the problem that meets the needs of various stakeholders and creates values.

The project was divided into three phases with the first focusing on research, user needs, and market character. Students were tasked with brainstorming and selecting a problem relating to their theme to base their design project on. Students developed a research plan, end user needs, market character, and sketches of their prototype. The second phase of the project was focused on the preliminary design. Students began writing their Conference paper addressing the problem, end users/stakeholders, social and economic value, methodology, research results, discussions, and conclusions. They also were tasked in providing a visualization of their proposed prototype utilizing SolidWorks. The last phase of the project concentrated on the detailed design relating to prototyping, verification, and validation. Students were to provide a detailed, complete set of drawings of the device prototype along with a bill of materials. Lastly, they were to complete a detailed conference paper, poster, project website, and prototype to present at the end of year showcase interacting with judges and a public audience.

The course was modified for Spring 2023 to be more open-ended. Prior to this course offering, all students designed a nanotechnology device that was to detect a disease of their choice. The closed nature of that project resulted in designs that were very similar to one another and did not spark the creativity and curiosity that we were desiring from the students. Allowing students to choose their project was intended to promote more engagement with the project and allow students to explore the topics they were interested in.

Methods

The goal of the concept mapping assignment in the course was to allow students an opportunity to reflect on their design experience and the mindset they were developing throughout the process. From a curriculum development standpoint, we were interested if the concepts that students identify as part of EM align with the first-year programs goals and objectives in this new format of the course. Additionally, we are interested in whether or not the concepts that students include in the concept maps and the connections they create between concepts shows growth before and after completing an open-ended design project.

In order to assess concept maps an automated scoring tool [24] was used to complete both traditional and categorical scoring. This scoring tool was developed for maps with the

Entrepreneurial Mindset as the central topic, although it can be modified for any topic. For the categorical scoring, the automated tool uses a word bank with the 6 categories related to EM listed below in Table 1 and assigns all known words to the appropriate category. For any word that did not appear in the word bank, the scoring tool asks the user to select the appropriate category. An option of no category is also allowed and should be used for any concepts that do not fit into the pre-defined categories.

Table 1: Predefined categories used by the automated scoring tool for Entrepreneurial Mindset

Codebook Categories
Business
Creating Value
Design Process
Education
Innovation
Knowledge Skills & Attributes

Results and Discussion

Traditional Scoring – Automated Scoring Tool

Using the traditional scoring option in the automated scoring tool the concepts were analyzed from the initial concept maps to the final concept maps. While the assignment asked students to iterate on their concept maps and it was assumed that they would add to the maps, it was possible for students to submit the exact same map or to modify their existing map to remove items or connections that they no longer considered to be a part of the Entrepreneurial Mindset. There were 32 concept maps from students who consented to participate in the study and completed an initial and subsequent final concept map. Table 2 compares the initial and final maps using the traditional total score, the number of concepts, the highest hierarchy and the number of cross links. In all cases the final maps did not decrease in any of the categories from the initial maps. All four of these comparisons were found to have statistically significant positive differences ($p<=.001$) using a Wilcoxon Signed Rank Test, a nonparametric test for related samples. On average, the score increased by about 17.6 points and there were only 4 maps that had no difference in final total score. The traditional total scores for are shown in Figure 2 for the initial and final concept maps. From the remaining sub-categories of the traditional scoring method, the most common way students modified their maps from the initial to the final version was to add concepts to the map. While the difference in cross links and highest hierarchy was a small increase from the initial to the final there are significantly more maps that remained unchanged in these categories. This means that in a majority of maps these new concepts might have been a new hierarchy with no new cross links or additions to the prior hierarchies or they could be additions to a prior smaller hierarchy with no new cross links and not enough new concepts to increase the highest hierarchy. While it is positive that students identified more concepts that exist within EM, being able to place these new concepts within the previous ones and make those connections to other topics is important to gain the metacognitive benefits of concept mapping.

Table 2: Traditional scoring comparisons from the initial map to final map

	Initial (avg)	Final (avg)	# of maps w/ no difference	p value
Total Score	51.8	69.4	4	p<0.001
Number of Concepts	12.3	16.9	5	p<0.001
Highest Hierarchy	3.2	3.8	19	p<0.001
Number of Cross Links	2.4	3.4	19	p=0.001

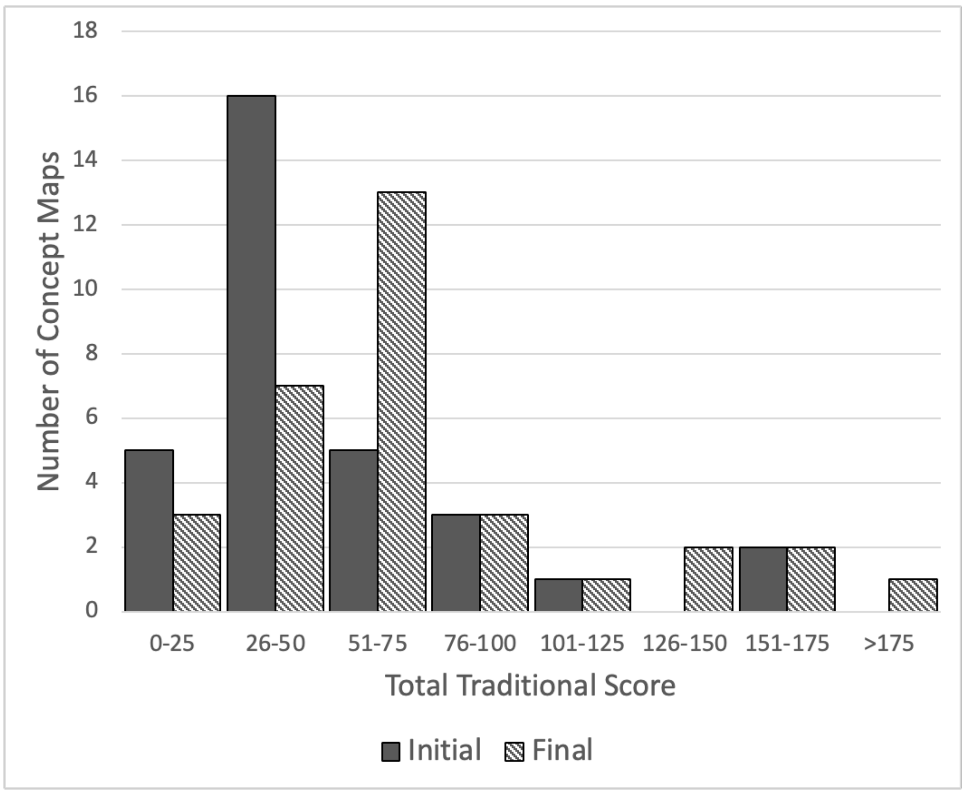

Figure 2: Total Traditional Scores

Categorical Scoring – Automated Scoring Tool

In order to examine the content shifts between the initial and final concept maps the categorical scoring feature of the automated scoring tool was used. A subset of five participants were chosen for this analysis. These five participants had the highest change in total score from initial to final map using the traditional scoring method. Each of these maps was scored using the scoring tool by two researchers. Since part of the goal was to try out the automated scoring tool a researcher familiar with the codebook and one less familiar with it ahead of time were selected. While the automated scoring tool should result in more similarities between scorers, the tool still requires some manual input and decision making for words that did not appear in the word bank. After scoring the five initial and five final maps an inter-rater reliability test was conducted and resulted in moderate reliability with a Cohen's Kappa of 0.416. This agreement includes the items that were automatically scored. After discussion among the researchers, it was decided to use the results from the researcher more familiar with the codebook. This highlights the continued struggle to achieve consistency with the automated tool without significant training and calibration. The number of concepts, number of interlinks, and total categorical score were found to have statistically significant positive differences ($p<0.05$) using a Wilcoxon Signed Rank Test, a nonparametric test for related samples. The results are shown in Table 3. On average, the categorical score increased by about 33.6.

Table 3: Categorical scoring comparisons from the initial map to final map

	Initial (avg)	**Final (avg)**	**p value**
Total Score	23.9	57.5	p=0.043
Number of Concepts Categorized	9.2	14.6	p=0.041
Number of Categories	3.2	3.6	p=0.157
Number of Interlinks	7.8	14	p=0.042

In order to examine what categories were being used across the maps, the five final map categorical scoring results were combined and Figure 3 shows a pie chart of the breakdown of categories across the five maps. Note that even though on average the maps only included 3-4 categories, across the five maps all six categories were used. The largest categories were Design Process and Knowledge Skills and Attributes accounting for over 60% of the categories used across all the concept maps. This is interesting since a lot of the class content was focused on the design project but also value creation. It is surprising the elements of value creation did not appear more in the maps.

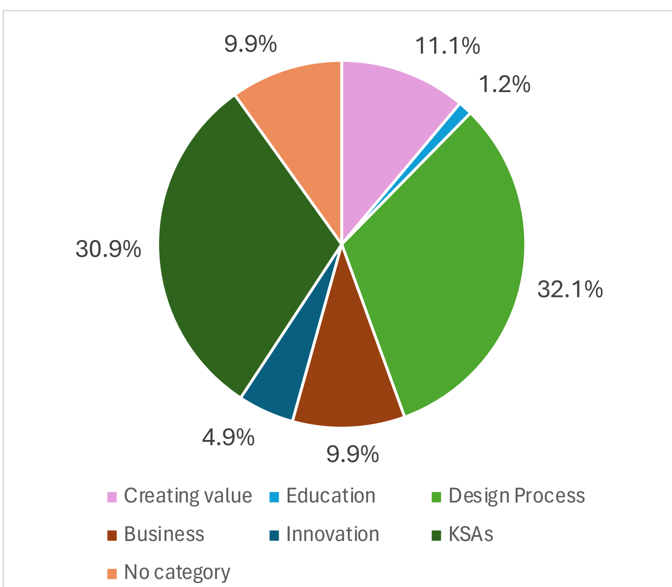

Figure 3: Final map categorical breakdown (n=5)

Since one of the goals of this was to look at what concepts students added to their map after their experience in the design course. To do this we looked at only the categories that were added to the five participants maps. Below is a pie chart, in Figure 4, showing the percentage of new concepts in each of the six categories. From this we can see that the participants added concepts in all of the categories, but quite a few of the concepts added were considered uncategorized. One thing to note that just because the concept was uncategorized does not mean it was not a valuable addition to the map but rather that it did not directly relate to the Entrepreneurial Mindset even if it did relate to other topics on the map where it was added.

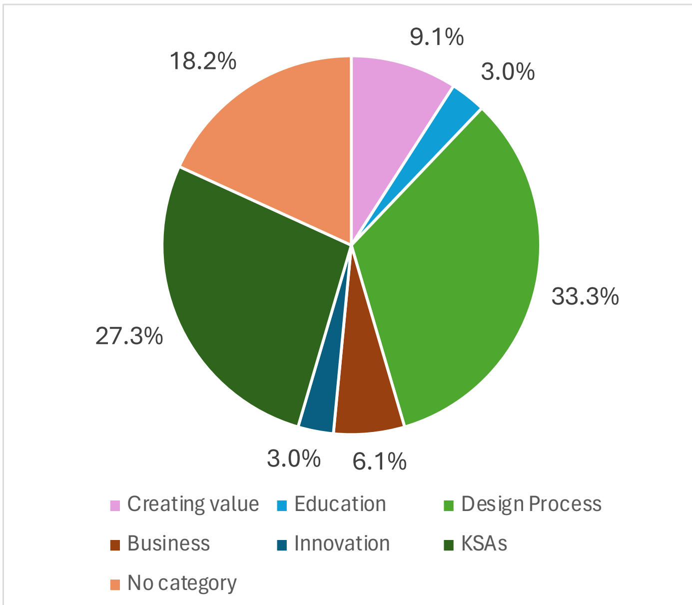

Figure 4: Final map categorical additions (n=5)

Conclusion and Future Work

It was hoped that the scores would increase between the initial and the final map given the assignment instructions and they did increase. Although it was also clear that students may have put in different levels of effort into the assignment. Given the results, modifications to the assignment may be given in future iterations to get a more consistent effort across the courses. One interesting result was how little the business category was used in the maps. Given that typically the word Entrepreneurial invokes ideas of start-ups, this was clearly not the major theme in the concept-maps. This is encouraging as creating start-ups is not the educational objective around including EM in these first-year engineering courses. This assignment will continue to provide insight to the course instructors by highlighting what students are considering when they reflect on the mindset they are using within their design projects.

With respect to using the automated scoring tool it is clearly an efficient way to do the traditional scoring process. However, the categorical scoring still required quite a bit of user input. The researchers felt the tool was easy to learn to use, but there were some user interface issues that caused problems. For example, when the list of concepts that needed manual categorization was long it required scrolling on the screen, but it wasn't immediately obvious when that was the case. This could cause a user to inadvertently press the button that it was complete before scrolling and thus assign "no category" to many of the concepts that they missed. Also, it was necessary to have the concept map up while manually categorizing because the meaning of words can change based on their placement within the map. Therefore, it might be helpful if the map was able to be shown within the tool rather than having to open a separate application. This feedback will be provided to the the automated scoring tool development team to see if there are additional elements that can be added to improve the user experience.

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