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”Mapping” the Landscape of First-Year Engineering Students’ Conceptualizations of Ethical Decision Making

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Mike's research concerns how people think and learning, and specifically how technology can enhance the way people think and learn. His NSF-funded project, GEEWIS (http://www.geewis.uconn.edu/), focused on streaming real-time water quality pond data via the Internet and providing support for the integration of this authentic data into secondary and higher education science classrooms. His approach features the analysis of log files, "dribble files," that maintain time-stamped listing of navigation choices and lag time. This approach has been applied to hypertext reading (Spencer Foundation grant), videodisc-based problem solving (Jasper project), and online navigation (Jason project). Recent work concerns playful learning using video game, card games, and board games aligned with national teaching and learning standards.

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Abstract

When working in a professional world, engineers often encounter problems that involve social and ethical considerations that cannot be solved using the technical skills that make up a majority of their engineering education. When encountering ethical challenges, an engineer should have ethical awareness and be reflective on the ethical implications of their decisions. It is important for universities to focus on improving their students’ ethical reasoning and social awareness if they want to develop successful engineering graduates that are ready to take on the challenges of the professional world. One way that the instruction of engineering ethics can improve is through increasing the understanding of prior knowledge that the students have. This will allow educators to create a better and more focused curriculum. This NSF-funded research study investigates how first-year engineering students conceptualize ethics and ethical decision making through the completion and analysis of concept maps.

Concept maps have been used for many years to illustrate an individual’s or a group’s topic knowledge. Concept maps have also been used at the start of a lesson to gain a baseline of students’ understanding. 225 first-year students from University of Connecticut, Rowan University, and University of Pittsburgh were asked to create concept maps of “ethical decision making” in engineering at the beginning of the 2020/2021 academic year. We analyzed the concept maps using both qualitative and quantitative approaches to gain a baseline measure of students' ethical awareness and decision making in selected contexts. Using the CMapsTools™ web tool, we analyzed the maps based on size, quality, and structure. The concept maps were then analyzed using text analysis to identify common words and concepts. Some patterns observed were that students do not include many links between concepts and therefore may have a low understanding of how such concepts are related. Students also leave out many important concepts in engineering ethics such as codes of ethics and ethical frameworks. With the knowledge gained from this research, first-year engineering programs can better explore how incoming students view decision-making and design more effective instructional practices.

Background

Introduction

Ethics is the “standards of conduct that apply to everyone” [1]. It is the difference between right and wrong. People use ethics to determine how to act when confronted with any situation; asking questions such as “who will this benefit?”, “who will this harm?”, and “what are the consequences?”. However, engineering ethics is different from everyday ethics. Engineering ethics are a set of professional ethics, or “those special morally permissible standards of conduct that, ideally, every member of a profession wants every other member to follow” [1]. These are found in codes of ethics created by governing bodies such as the National Society of Professional Engineers (NSPE). Engineering ethics may be difficult to conceptualize due to engineers being removed in time and space from the consequences of their work or not learning engineering ethics in context. This may lead to engineers not accurately assessing the ethical implications of their choices on a project.

Ethical awareness and reasoning are crucial parts of the creation of a successful engineer [2]. Situations occur within the engineering space that cause one to assess what action is their ethical responsibility due to the fact that they have a direct impact on society [2]. Many widely reported failures in the engineering community have been influenced by lapses in ethical judgement, such as the VW scandal [3], the Boeing crashes [4], and the Florida International University bridge collapse [5]. Thus, engineering institutions should make it a priority to aid in the moral development and ethical awareness of its students throughout the curriculum. Students will often approach the area of engineering ethics (and ethical decision-making) from different perspectives based on past experiences and value systems. For instructors to build upon what students understand in terms of ethical decision making, it is crucial to get a baseline measure of how students actually conceptualize such a topic through targeted assessment.

Related Literature

Three of the most common strategies for implementing ethics education in a curriculum are a stand-alone ethics course taught by a professor outside of the engineering discipline, embedding it within another course or across multiple courses within a curriculum, or a team teaching style [6] [7]. Many faculty members express that there is an ease to having a separate course for ethics taught by an ethics professor. However, some present a flaw in stand-alone courses taught by non-engineering faculty, indicating that these methods can lead to students disconnecting the ethics education from professional engineering and undervaluing what they are learning [8]. Another potential flaw is present with a cross-curriculum approach as it relies on the instructor's willingness to incorporate ethics into their course and may lack depth or continuity when split into separate classes [7].

One of the most common and effective ways of teaching engineering ethics is through case studies [6] [7] [9]. Research suggests that case studies can benefit students by allowing them to encounter ethical situations in a real engineering context, exploring many different decisions to a situation, opening a discourse of different perspectives from students, as well as, allowing students to compare acceptable and unacceptable decisions within a situation and strengthen their ethical reasoning skills [6].

To improve the way in which engineering ethics is taught, there needs to be a better understanding of how engineering students conceptualize ethical decision making and reasoning when they begin college. Faculty often utilize the strategy of assessing prior knowledge of their students to influence their course structure, assignments, or even their teaching style. This allows instructors to better gauge what topics need to be (re)taught, what skills need to be further developed, and how to tailor instruction around students' current understanding of topic areas. There are many ways to assess students' prior knowledge in areas such as engineering ethics. Some common assessment tools for engineering ethics are student self-reporting, the Defining Issues Test 2 (DIT-2), Engineering Ethical Reasoning Instrument (EERI), Moral Foundations Questionnaire (MFQ), and the ethics questions used on the Fundamentals of Engineering Exam [10]. However, each one of these methods have drawbacks. The student self-reporting method may not be accurate due to their own perceptions not aligning with their behavior. The Fundamentals of Engineering Exam was created for professional engineers and therefore is too advanced for first-year engineering students. The MFQ shows a student's reliance on the foundations of morality which is not part of the scope of this study. Finally, the EERI and DIT-2 can display a student's ethical judgement, but not a student's prior understanding or knowledge on the topic of ethics. Due to these drawbacks, we decided to utilize concept maps to assess students' understanding of ethical decision-making.

A concept map is "a tool for people of all ages and all domains of knowledge to express their understanding about a topic" [11]. They are used by instructors to assist in the education of their students whether they are used at the beginning, during, or after studying the topic. Concept maps can be analyzed as a way of assessing a student's knowledge and conceptualization of a topic [12]. The traditional method of scoring creates a score based on number of concepts, highest level of hierarchy, and number of interconnections which will be explained in the methods section [12]. This score is seen to be a reference for how well a student understands the topic. Watson, Barrella, and Pelkey (2018) created a program that was able to calculate digital concept maps to analyze more efficiently [13]. However, it has been noted that the program is unable to analyze for correctness.

This study is designed to use concept maps as an instrument for assessing how first-year engineering students conceptualize ethical decision-making. We intend to answer the following research question as part of this NSF study:

How do first-year engineering students conceptualize ethics and ethical decision making?

While there are many studies that investigate engineering ethics and its instructional strategies, more research is needed on understanding student perceptions of ethics as they enter the college classroom [6][7][9]. There is also a lack of research that leverages concept maps as an assessment tool in this area of research, which further contributes to our understanding of students' mental framework around ethics. With this assessment strategy that allows for students to clearly represent their prior knowledge and understanding of the topic, instructors may find valuable information on how to structure their lessons, course, or curriculum.

Methods

Study Design

This study utilized concept maps from 225 first-year engineering students from University of Connecticut, Rowan University, and University of Pittsburgh, comprising both general engineering students and those who have declared their engineering discipline. The students completed concept maps on "ethical decision making" as an assignment at the beginning of a required first-year engineering course, before receiving any instruction on the topic. These concept maps were created using the CmapTools program [14]. The students received instruction on how to create a concept map before creating their first map (See Appendix A). The study involves researchers from all three universities and was approved by the institutional review board (IRB) at all three institutions (IRB# PRO-2020-48).

Concept Map Scoring

The concept maps were scored using the traditional scoring method using the CmapParse developed by Watson, Barrella, and Pelkey (2018) [13]. Concept maps follow a standard format in which a starting topic is placed in the middle and adding concepts that relate to the topic. The concepts are connected with links to express the relationships between them. The units of a concept map that are utilized in the traditional scoring method are the number of concepts, hierarchies, and crosslinks. Hierarchies are concepts that are directly branching from the starting topic. Levels of a hierarchy are the number of concepts down the longest path of a hierarchy. Crosslinks are links between hierarchies. Watson and her team (2016) adapted Novak and Canas to make a model that clearly visualizes the components of a concept map (See Figure 1) [12].

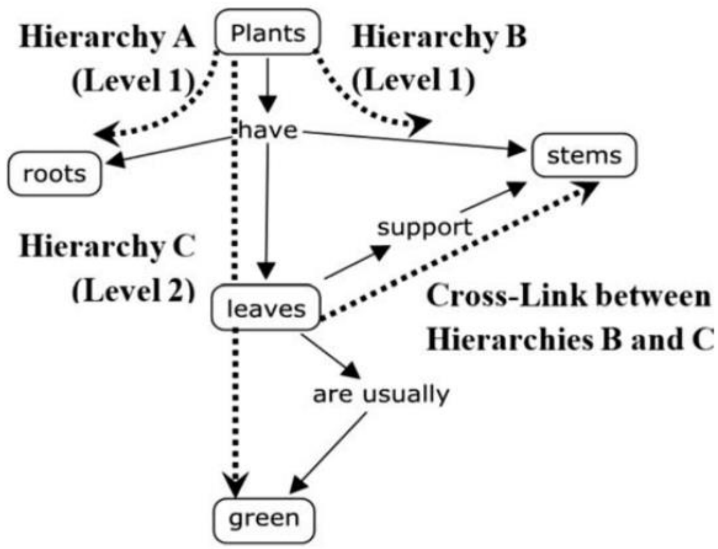

Figure 1. Breakdown of Concept Map [12]

Traditional scoring assigns a numerical value to a concept map based on its size and structure. In traditional scoring, concepts are worth 1 point, 5 points are given for each level of the highest hierarchy, and individual crosslinks are worth 10 points.

Equation 1: Traditional Scoring

$$\text{Total} = (NC - NCL) + (HH) \times 5 + (NCL) \times 10$$

Note: NC = Number of concepts, NCL = Number of crosslinks, HH = Highest level of hierarchy

The size of a concept map can be found by looking at the number of concepts while the hierarchies and crosslinks showcase the structure of a concept map. After being scored, the text of the concept maps was analyzed by looking at the frequency of each word and concept in the concept maps and identifying emerging themes. All of the concept maps were converted to text files and uploaded to Excel. The text was then split into each individual word and the frequencies of their use in all concept maps were calculated. All dispensable words such as “and”, “the”, or “to” were removed from the list. Finally, the concept maps that used each of the common words were identified and counted, resulting in the number of individual students that used each common word. Due to time constraints, the concept maps were not able to be qualitatively analyzed, however; this will be carried out in the future as the project is ongoing.

Results and Discussion

Traditional Scoring

All of the concept maps that were collected and analyzed using the CmapParse program were then compiled into SPSS Statistics to examine the students' understanding of ethical decision-making. This process outputs the number of concepts, number of hierarchies, highest level of hierarchy, and number of crosslinks as well as the combined traditional score. The descriptive statistics and histogram of this data are presented in Table 1 and Figure 2. Further histograms are provided in Appendix B.

Table 1. Descriptive statistics for concept map analysis

Variable	Mean	SD	Minimum	Maximum
Number of Concepts	16.30	7.25	3	45
Number of Hierarchies	5.34	3.67	1	25
Highest Hierarchy	3.38	1.74	1	12
Number of Crosslinks	1.77	3.50	0	28
Traditional Score	49.15	39.40	8	304

Note. SD = Standard Deviation

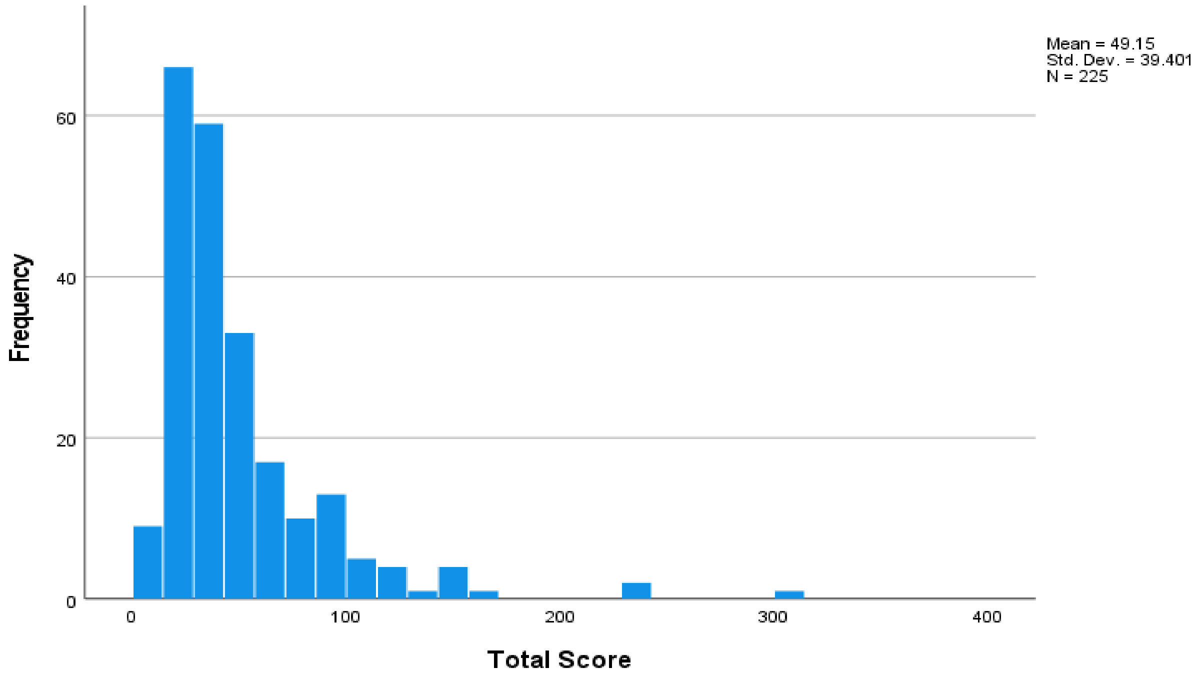

Figure 2. Histogram of Traditional Score

Here it can be seen that the overall traditional score averages to around 49 points; however, the standard deviation shows variation between students, and the maximum score is much higher at 304. The traditional score is skewed right and shows that there are a large number of students who approach ethics and ethical decision making at a beginner level. The most important information that can be gathered from this data, however, is the low number of crosslinks. Rittle-Johnson (2006) expresses that conceptual knowledge is not just facts and concepts known, but also how the concepts are interrelated [15]. Star (2005) also states that conceptual knowledge is defined by the "richness of the connections" [16]. The average number of crosslinks is 1.77, although the standard deviation is 3.5 which expresses a large variation. However, a majority of the students include very few crosslinks with 68.9% having less than 2 crosslinks in their concept map. This shows that although some students may have knowledge on certain areas of ethics or ethical decision making, they may not fully understand how they are related or interact with each other. Another possibility is that students did not spend much time or effort on this assignment. This is helpful for instructors because it shows that there should be a focus on the interrelation of topics when teaching engineering ethics. Strategies such as using case studies can reinforce connections between areas such as identifying characters and facts, considering consequences, acknowledging biases, and recognize codes of ethics and internal values [17]. Showing how concepts relate to each other and effect each other can give students a deeper understanding of ethics and ethical reasoning [18]

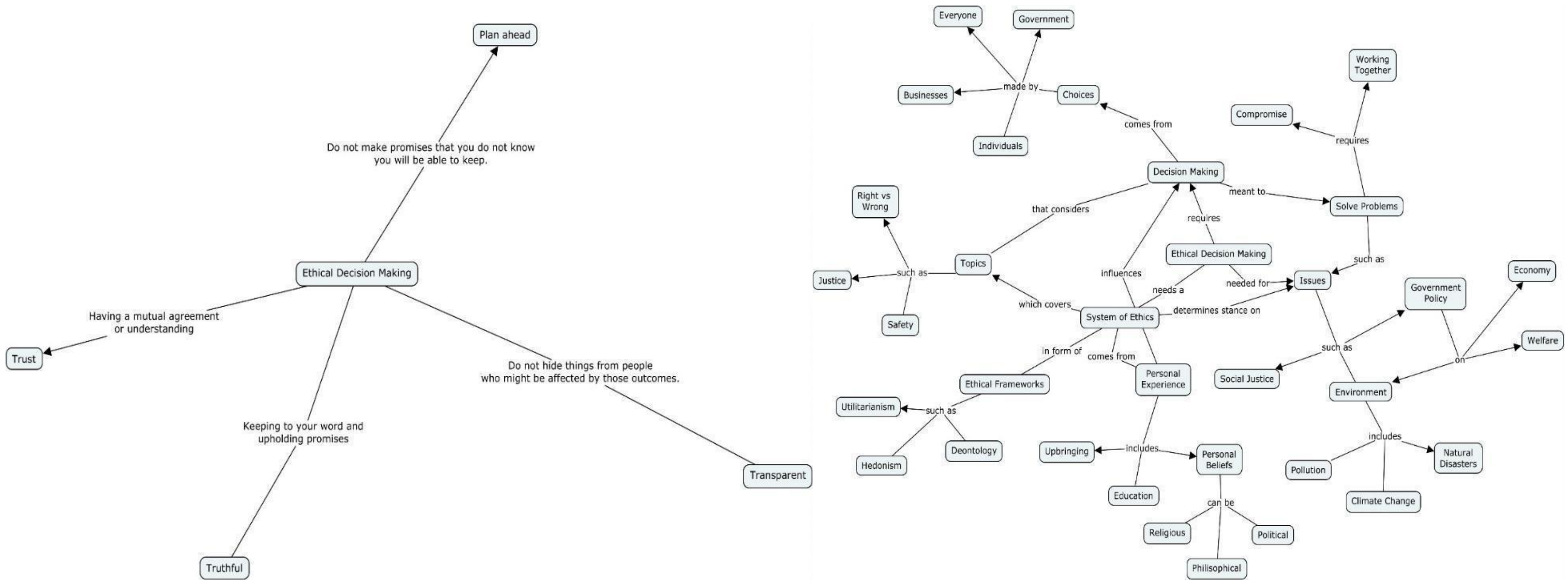

Figure 3. Example of Low Scoring Maps (left - 9 pts) Vs. High Scoring Maps (right - 110 pts)

When examining the different scoring concept maps it is easy to notice a difference in size from low having few concepts and the high having the most concepts. However, it is important to note some of the other aspects that differentiate these concept maps. As the maps increase in score they also increase in the number of hierarchies and levels in each hierarchy. The biggest difference however is the number of crosslinks between concepts. This shows that the student has a deeper understanding and conceptual knowledge of the topic.

Text Analysis

The text analysis was used to identify common concepts and words that are used throughout the concept maps. Figure 4 shows a word cloud that represents many of the common words and themes that students included in their concept maps.

Figure 4. Word Cloud of Common Concepts

Table 2 shows the top 10 most common words and the number of students that included them.

Table 2. Text analysis of concept maps

Concept	% of students
Moral(s)	45.8
Right	34.2
Others	28
Wrong	27.6
Values	26.7
Personal	22.7
Good	22.7
Work	22.2
Problem	21.3
Consequence(s)	18.7

Hess (2018) identifies the learning goals that are the most prominent in engineering ethics education are ethical awareness and ethical decision-making [9]. A study conducted by Loendorf (2009) expresses that students often do not have a complete understanding of concept and procedures necessary for ethical decision making and that the earlier they encounter engineering ethics education, the more prepared they will be to handle an ethical situation [17]. The data gathered from text analysis that is represented above is valuable for understanding the level of knowledge that students have when approaching these learning goals in their first year. The results when all of the concept maps were analyzed show that many students have a basic understanding of ethics and ethical decision making with focus on concepts such as "moral" or "right" and "wrong". Students also have an understanding of characters that play a role in ethical situations with concepts such as "others" and "consequences". Finally, the students also have some understanding of the relativity of ethics with concepts such as "personal" and "values" which show that everyone views the situation from their own perspective with their own values. This information gives a strong baseline for instructors to use when assessing students' prior knowledge. That is not the only useful information that can be obtained from this data. It can also be helpful to notice what concepts are not as well recognized, such as "codes of ethics" or "ethical frameworks". These are concepts that are paramount in the field of engineering ethics and must be focused on through instruction [19]. Codes and ethical frameworks can then be taught in many ways and then reinforced through applying them when responding to case studies [17].

Following the overall text analysis, the top and bottom 25% traditional scoring concept maps were analyzed separately in the same way (see Table 3). This was done to explore the difference in concepts between those with simple understandings of ethics to students with more complex understandings of ethics. This number was chosen so that it represents the lower and higher quartiles of the traditional score while including maps that have the same score.

Table 3. Text analysis of high scoring vs low scoring concept maps

High Traditional Score (n=64)		Low Traditional Score (n=64)	
Concept	% of students	Concept	% of students
Moral(s)	48.4	Moral(s)	42.2
Right	40.6	Right	31.3
Wrong	34.4	Others	28.2
Values	32.8	People	25
People	31.3	Values	21.9
Personal	31.3	Wrong	21.9
Good	***31.3***	***Consider***	***20.3***
Others	25	***Problem***	***20.3***
Consequence(s)	***25***	Personal	18.8
Law(s)	***23.4***	***Respect***	***18.8***

Note: Highlights show concepts that differ from each group.

When the data was split to represent the low and high scoring concept maps, it can be seen that the common concepts are similar with them sharing 7 of the top 10 concepts. It is worth noting that the number of students who include the most frequent concepts also score consistently higher on the quantitative traditional scoring. The higher scoring concept maps also have a higher frequency of concepts that focus on the elements surrounding an ethical decision such as "consequences" and laws" while the lower scoring maps have more low-level concepts such as "problem" and "consider". This suggests that the higher scoring students have a better understanding of the strategies that are used to determine the best course of action, such as considering the consequences and identifying laws that pertain to an ethical situation [20].

Summary and Future Work

The National Society of Professional Engineers expresses that ethics and ethical decision making are important aspects of engineering. As part of the education of engineers, it is important for institutions to focus on these areas to give students the tools to become successful engineers. This study was designed to understand how first-year students conceptualize ethics and ethical decision making. Concept maps were used to assess the level of understanding that the participants had on the topic "ethical decision making". Concept maps from 225 first-year engineering students across three universities were analyzed with both traditional scoring and text analysis.

The concept maps were able to provide a stronger understanding of the prior knowledge that students have on the topic of ethics and ethical decision making. It shows that the students have a rudimentary understanding of ethics with little understanding of the relationship between concepts and topics under the umbrella of ethics. The text analysis shows the pre-existing concepts that students have on a subject as well as what concepts are lacking such as "codes of ethics" and "ethical frameworks". This can be helpful in giving a baseline for instructors' assessment of student prior knowledge as well as showing areas that need to be taught or improved through their instruction.

This study will be continued by researchers through the further analysis of the concept maps. The concept maps will be investigated through holistic scoring which is a qualitative analysis strategy that assigns a score based on comprehensiveness, organization, and correctness. A concept map on this topic has also been created by a group of researchers in the field of engineering ethics and engineering education. A preliminary comparison has been conducted with this "expert" concept map and the student maps. It shows that students have some understanding of the concepts of ethics such as "values" and consequences such as who will benefit or be harmed. It also shows they are lacking in many areas such as codes of ethics, checking biases, and identifying stakeholders. Further analysis with the expert concept map will be conducted as the project progresses. This will then be combined with ethical reasoning assessment data gathered from Engineering Ethics Reasoning Instrument (EERI) and the Defining Issues Test 2 (DIT2) to gain a deeper understanding of first-year students ethical reasoning and how it relates to their conceptions on ethical decision making . Students will also be tasked with creating concept maps at the end of the first-year as a way to assess the change (or lack thereof) in students' conceptualization of ethical decision making after formal instruction on the topic.

Acknowledgements

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Appendix A – Ethical Decision Making Assignment Instructions

<u>Directions</u>

1. We are asking first-year engineering students to develop a concept map of "ethical decision making" at the beginning and end of the 2020/2021 academic year. This will enable us, the research team, to see how students' conceptualizations of ethics changes throughout the first year.
2. Students will first brainstorm individually all possible things about ethical decision making that comes to their mind. This can be done informally by asking students to write concepts and ideas on a sheet of paper.
3. Next, you should explain how to develop a concept map by developing a map of your own! You can choose any topic of interest but we suggest the concept "French Fry". This can be done as a class activity (see attached example).
4. Students will then have time to develop their own concept maps around ethical decision making.
5. Students may use a blank sheet of paper to draft their concept map, but they are required to use the "C-Map" software to create their map!
    1. Google "cmaps.ihmc" and select the first link "Cmap-IHMC"
    2. Follow the C-Map Instructions for how to use the software!
    3. The link is also supplied on the bottom of this page!
    4. PowerPoint Concept Map Overview (https://drive.google.com/file/d/1hQPTMxFBjC55E6KOZMAoLGSn2eADHnwI/view?usp=sharing), Engineering Unleashed Faculty Development (engineeringunleashed.com)
    5. Cmap Concept Map Construction (https://drive.google.com/file/d/15gAzHjE7yRF3fMiuIf-ywJ_6_6__AXVF/view?usp=sharing), Engineering Unleashed Faculty Development (engineeringunleashed.com)

Please construct a **concept map** starting with anything related to the **ethical decision making.** Expand on your ideas as much as possible.

Appendix B – Descriptive Histograms of Concept Map Scores

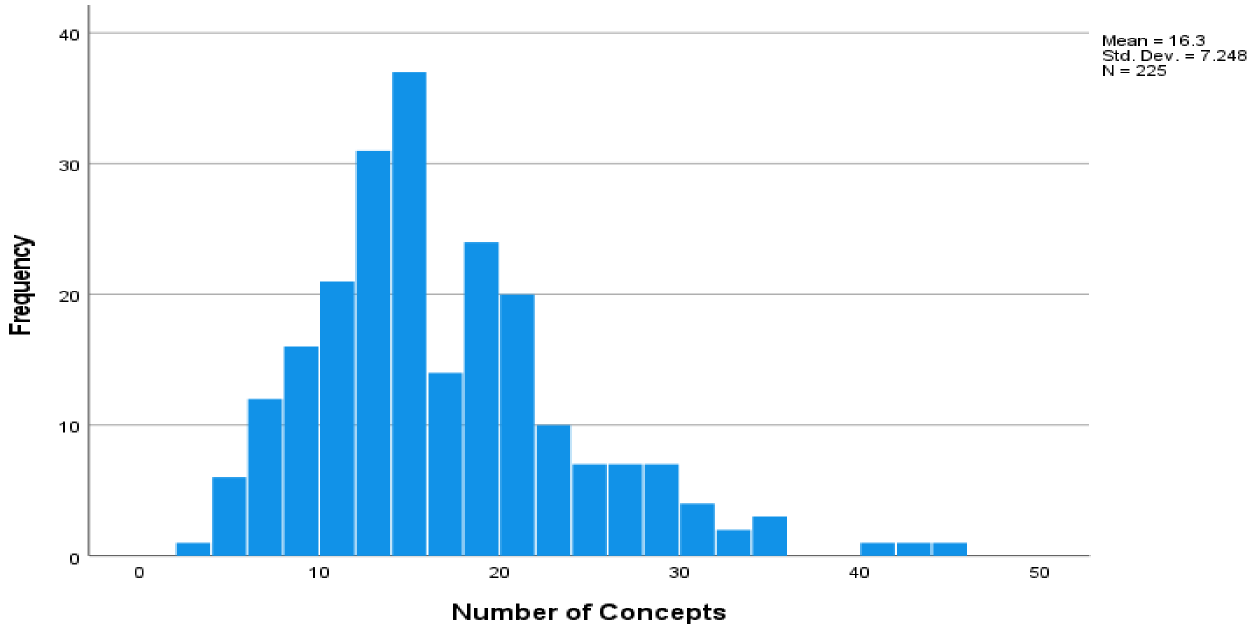

Figure B1. Histogram of Number of Concepts

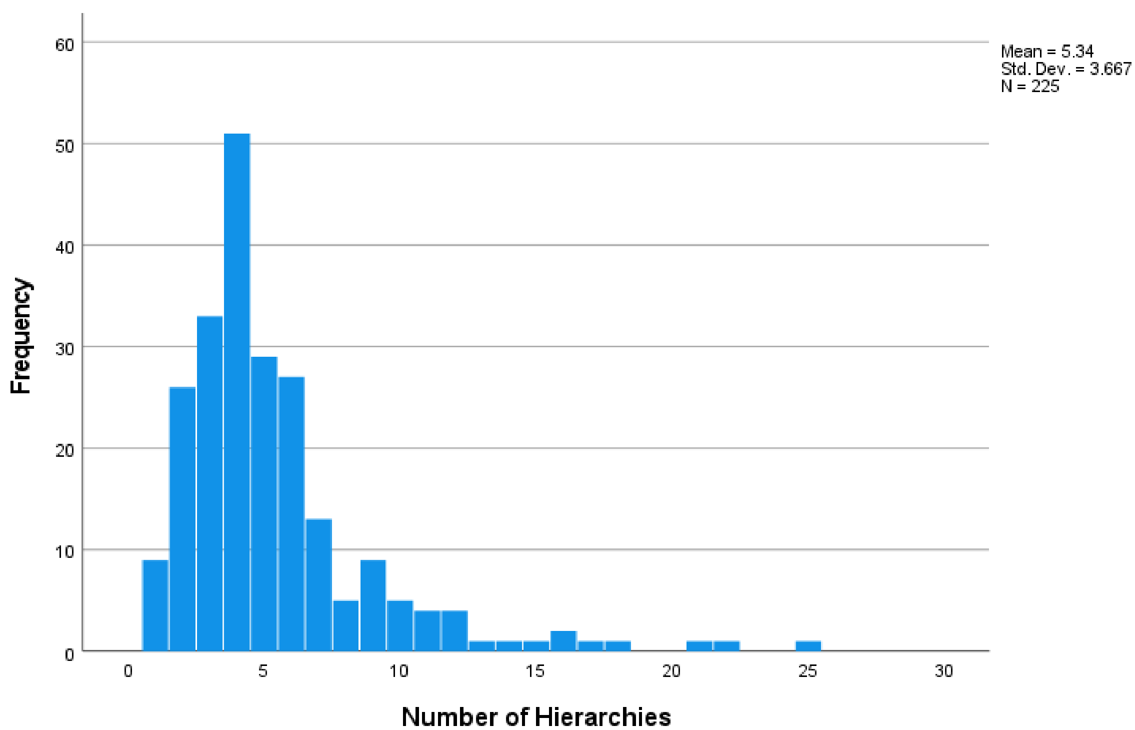

Figure B2. Histogram of Number of Hierarchies

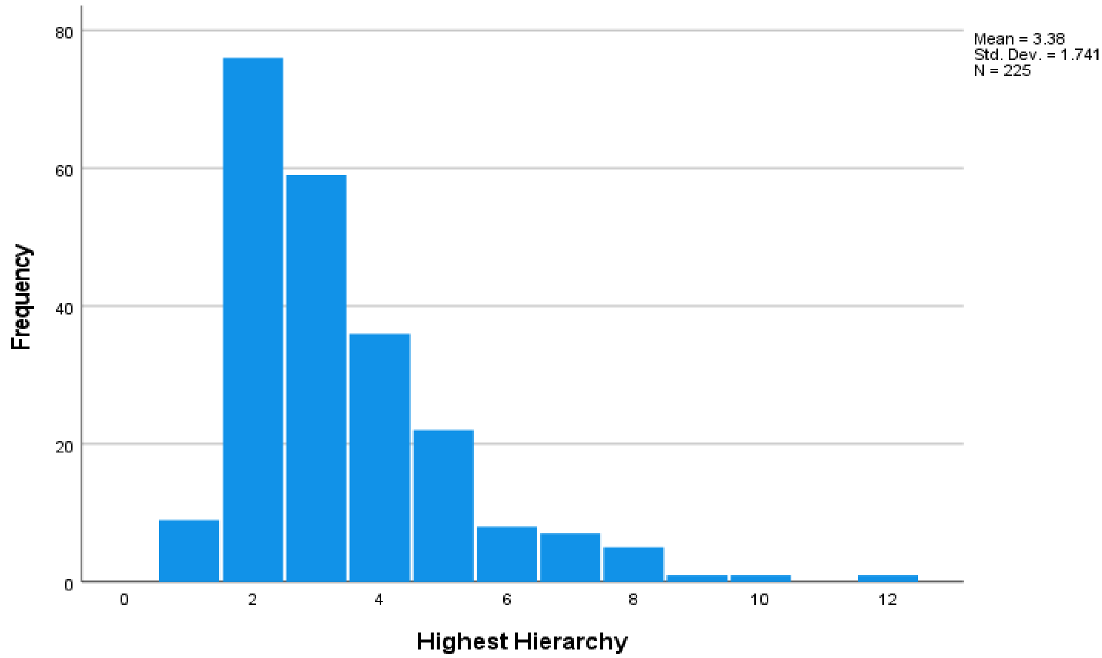

Figure B3. Histogram of Highest Hierarchy

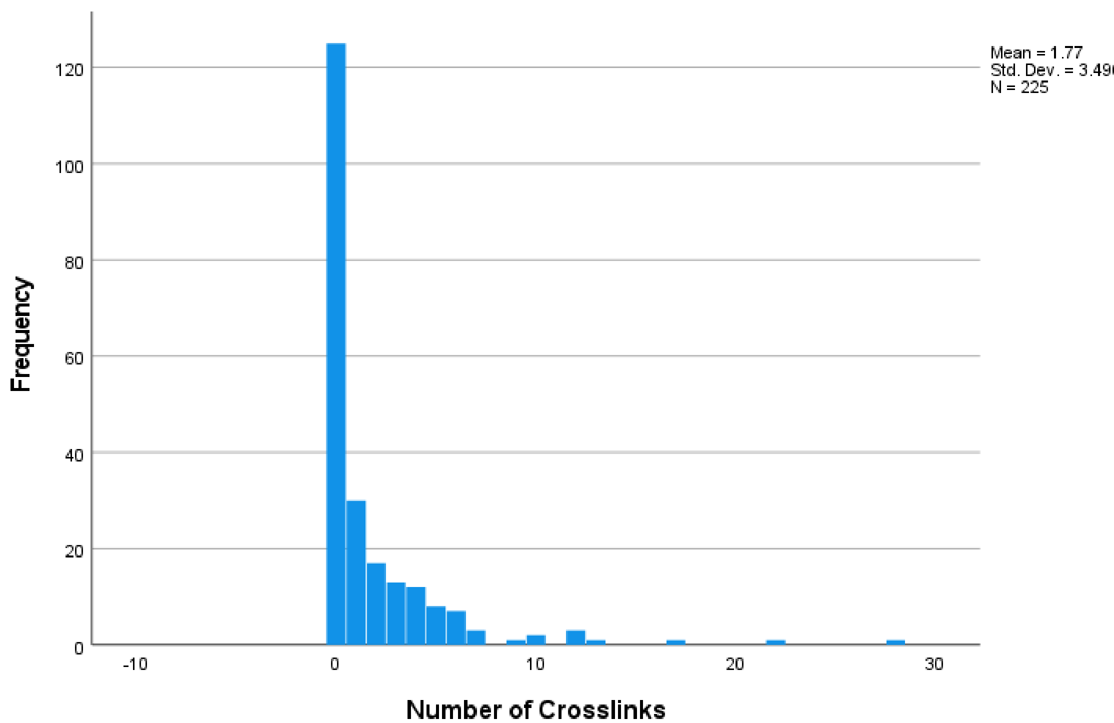

Figure B4. Histogram of Number of Crosslinks