AC 2012-3118: THE IMPACT OF COGNITIVE STYLE ON CONCEPT MAPPING: VISUALIZING VARIATIONS IN THE STRUCTURE OF IDEAS

Dr. Joanna F. DeFranco, Pennsylvania State University, Great Valley

Joanna DeFranco earned her Ph.D. in computer and information science from New Jersey Institute of Technology, M.S. in computer engineering from Villanova University, and B.S. in electrical engineering from Penn State, University Park. She teaches graduate courses, including Problem Solving, Project Management, Software Systems Design, Computer Forensics, Ethics and Values in Science and Technology, Advanced Software Engineering Studio, and an Information Technology seminar. Previous to entering academia, DeFranco held a number of positions in industry and government, including Software Engineer for Motorola in Horsham, Penn., and an Electronics Engineer for the Naval Air Development Center in Warminster, Penn. She has published a number of articles in journals and conference proceedings in the area of collaborative problem solving, group cognition, e-learning, and global engineering.

Dr. Kathryn W. Jablokow, Penn State University

Kathryn Jablokow is Associate Professor of mechanical engineering and engineering design at Penn State University. A graduate of Ohio State University (electrical engineering), Jablokow's teaching and research interests include creativity, problem solving, and cognitive diversity in engineering, as well as robotics and computational dynamics. In addition to her membership in ASEE, she is a Senior Member of IEEE and a Fellow of ASME. Jablokow is the architect of a unique four-course graduate module focused on problem solving leadership and is currently developing a new methodology for cognition-based design. She founded and directs the Problem Solving Research Group, whose 50+ collaborating members include faculty and students from several universities, as well as industrial representatives, military leaders, and corporate consultants.

Dr. Sven G. Bilen, Pennsylvania State University, University Park

Sven G. Bilen is an Associate Professor of engineering design, electrical engineering, and aerospace engineering at Penn State and Head of the School of Engineering Design, Technology, and Professional Programs. His educational research interests include developing techniques for enhancing engineering design education, innovation in design, teaching technological entrepreneurship, global product design, and systems design.

Mr. Andras Gordon, Pennsylvania State University, University Park

Andras Gordon is an instructor of engineering design in the School of Engineering Design, Technology and Professional programs. He is interested in applications of systems thinking in introductory engineering design classes. He is also involved in optimizing ways of collaboration in virtual teams of engineering and other students in culturally diverse and geographically dispersed environment.

The Impact of Cognitive Style on Concept Mapping: Visualizing Variations in the Structure of Ideas

Abstract

The aim of this exploratory study was to determine whether any links exist between cognitive style and the ways in which students organize their ideas in concept maps. In particular, 77 undergraduate and 51 graduate engineering students completed separate concept maps based on "common knowledge" topics and relevant engineering course topics, respectively; this paper will focus on the "common knowledge" maps. The students' cognitive styles were assessed using the Kirton Adaption–Innovation inventory (KAI), and their concept maps were analyzed using both traditional and holistic scoring approaches. Correlations between the students' KAI results and the metrics obtained from their concept maps were investigated, with some statistically significant correlations observed. These results are discussed, along with the cognitive style distributions of our samples and implications of our findings for the engineering classroom.

1. Introduction

Concept mapping is a graphical technique used to represent an individual's knowledge and understanding about a topic. In concept maps, concepts are arranged in hierarchical patterns using labeled cross-links to connect the various branches and explain relationships (including causality) between the nodes (see Figure 1). The use of concept maps in engineering education research is growing, with applications in the assessment of knowledge mastery and integration within courses, programs, and across multiple disciplines.[1,5,10,13,16,17,18] Concept maps have also been shown to be particularly useful in the early stages of engineering problem solving and design.[3]

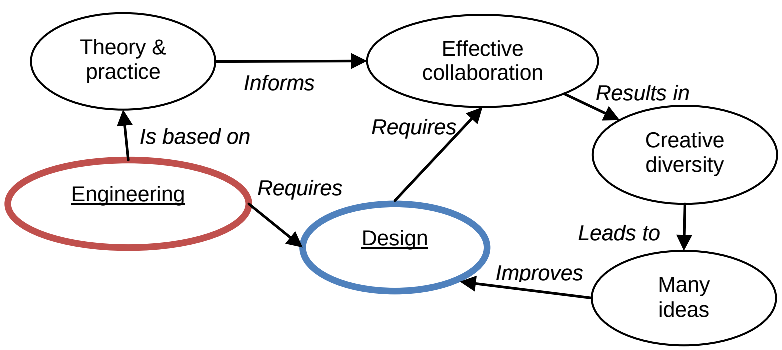


Figure 1: Example concept map

From a cognitive perspective, concept maps are typically used to tell us about the *cognitive level* of our students—i.e., *how much* they know about a particular topic and *how well* they can express that knowledge—but concept maps may have more to tell us if we explore them from other perspectives. In particular, we believe that the structure of a student's concept map may also give us important insights into that student's *cognitive style* (i.e., their *preference for managing structure*). In other words, cognitive style may influence how a student prefers to express or structure knowledge in a concept map to communicate what they know about a specific problem. If so, then having insight into that relationship may help us interpret a student's concept maps more effectively and accurately.

In essence, every problem an engineer faces has structure; that structure ranges from very tight (where there are few options to solve the problem) to very loose (where there are many options to solve the problem). An engineer's preference for structure (i.e., his/her cognitive style) will affect his/her comfort level in solving a particular problem, in addition to the way he/she communicates the details of that problem. Since concept mapping can be used to graphically communicate an individual's understanding of a problem, knowing whether (and how) a person's cognitive style affects the way a problem is mapped will be useful information.

To test our premise, we designed and performed a detailed experiment to study the impact of cognitive style on concept mapping. Cognitive style was assessed using the Kirton Adaption–Innovation inventory, or KAI, a well-established and highly validated psychometric instrument.[11] As measured by KAI, an individual's cognitive style falls along a continuum and is described as more adaptive or more innovative. Individuals who are more adaptive prefer more structure when problem solving, while more innovative individuals prefer less structure. (Note: here, we are using the word "innovative" as defined by Adaption–Innovation theory, not the popular process-oriented definition.) In complex problem solving, a diversity of styles is required to solve the wide diversity of problems we face today.

Following a brief review of the background literature in Section 2, this paper presents a summary of our investigation in Sections 3 and 4, including the experimental design, research methods, and scoring metrics to determine the impact of cognitive style on concept mapping. We close (in Sections 5 and 6) with a discussion of the implications of our results, limitations of the study, and planned future work based on our findings.

2. Background and Literature Review

With the increasing complexity of engineering problems, there are very few problems we can solve alone. As a result, understanding cognitive diversity and how it affects particular engineering artifacts is important within the context of engineering education.[7] Concept mapping is a tool used in many fields, including engineering, and it has been shown to be effective in assessing understanding and knowledge about a particular topic or problem.[2,3,13] We propose that cognitive style will affect the way in which concept mapping is utilized by individuals. Since cognitive styles vary among individuals, engineering teams are usually cognitively diverse in terms of style. Cognitive diversity must be managed when individuals come together to solve problems, and it must also be understood that each engineer may produce different artifacts in response to the same problem due to cognitive differences.

2.1 Concept Mapping

Concept mapping is a tool utilized to organize and represent knowledge.[14] Concept maps, as illustrated previously in Figure 1, include both concepts (nodes) and relationships (links) between the concepts, as well as linking phrases between concepts. Concept mapping is traditionally utilized to elicit and analyze a representation of knowledge. Its advantages include the fact that it is rather intuitive and it does not require much training for the person constructing the map. Concept mapping also offers many evaluation possibilities, ranging from simple counting of map characteristics to more involved calculations (e.g., map complexity). Traditionally, the evaluation of concept maps centers on evaluating a student's knowledge of a particular topic. In this research, we focused on evaluating the structure of concept maps to investigate the possibility of correlations with cognitive style. The analysis of concept maps is interesting in that the literature presents a variety of possible metrics to utilize. A discussion of the metrics we chose to evaluate our maps is presented below.

2.2 Scoring Metrics for Concept Maps

There are many possible metrics to consider when analyzing concept maps. As mentioned above, our focus here was on the way in which student concept maps are constructed and not the comprehension or correctness of the map topic; therefore, the metrics used in this analysis were chosen with that focus in mind. The metrics fell into two categories: traditional and holistic. The traditional metrics involved the straightforward counting of certain characteristics of the maps. The holistic metrics were more complex, in that they required some interpretation by the map evaluators.

2.2.1 Traditional Scoring Metrics

Concepts and links

The concepts used in a map are traditionally evaluated to determine a subject's understanding and knowledge of a topic. For example, the number of relevant concepts (to a particular topic) used in a map may be counted.[2] For the purposes of this study, the concepts were evaluated based on their total number and how many were used from a given list, as well as how many were unused and added by the research subjects. Similarly, the links (a.k.a. propositions) utilized in the map are traditionally assessed based on their validity (relative to the assigned topic). Our assessment focused on the number of links in the map to calculate both map density and map complexity.

Map density

Map density is calculated to assess the degree to which the map constructor was able to integrate the concepts together. It is defined as follows:[12]

$$\text{map density} = \frac{\text{links}}{\text{total concepts}(\text{total concepts} - 1)}. \qquad (1)$$

Map complexity

The map complexity ratio assesses the breadth of a concept map and is defined as follows:[9]

$$\text{map complexity} = \frac{\text{total links}}{\text{total concepts}}. \qquad (2)$$

2.2.2 Holistic Scoring Metrics

There are many holistic scoring methodologies described in the literature. We chose two methods that were most applicable to our study, i.e., *structure complexity* as utilized in Yin's study of two different concept mapping techniques,[15] and Besterfield-Sacre's use of *map structure* in her study of assessment rubrics.[1]

Map structure (dominant structure)

When it comes to the dominant structural pattern of a concept map, there five possibilities have been identified:[15] *linear* (concepts chained together), *circular* (concepts are daisy-chained with ends joined), *hub/spoke* (concepts originate from a center concept), *tree* (concepts are connected linearly with branches), and *network* (interconnected concepts). The dominant structure/pattern for each student concept map was evaluated based on the way the concepts were interconnected.

Hierarchies and crosslinks (structure complexity)

A hierarchy is defined as the extended levels that emanate from the main or topical concept of a map.[1] The hierarchies of the students' concept maps were evaluated in three ways: *total number* of hierarchies, the *highest level* among the hierarchies, and the *number of cross-links* (connections) between hierarchies. To be consistent, the evaluators agreed on the main concept of each map prior to counting the number of hierarchies. In general, once the number of hierarchies is determined, the highest level achieved among the hierarchies is recorded; finally, the number of cross-links is determined.

2.3 Cognitive Style Diversity

In general, cognitive style describes an individual's preference for the manner in which a problem is perceived, managed, and resolved; this includes the way the individual prefers to manage the structure of a problem. There are many different dimensions of cognitive style; here, we will focus on the dimension of cognitive style known as Adaption–Innovation (A–I).[8,11] In the A–I framework, cognitive style is defined on a bipolar continuum that ranges from high Adaption to high Innovation (see Figure 2). It is important to note that no one style on the continuum is "better" than any other. The key distinguishing factor between individuals who are more adaptive and those who are more innovative (using relative terms, as befits a continuous model) is the type and amount of structure they prefer when solving problems, however easy or difficult those problems may be (i.e., whatever their cognitive level).

In particular, the more adaptive prefer <u>more</u> structure when problem solving, with more of that structure consensually agreed, whereas the more innovative prefer <u>less</u> structure and are less concerned about achieving consensus around the structure they use. Said another way, the more adaptive prefer to work with and within existing guidelines or rules in order to achieve solutions that improve a system, whereas the more innovative are more likely to feel constrained by rules, preferring instead to operate at the edges of or even across structures in order to solve problems differently. Here, it is important to emphasize once again that the distinction between Adaption and Innovation is not one of dichotomy, but a spectrum of preference, which is far more useful (and realistic) for comparative purposes. Every individual is more adaptive when compared to some individuals and more innovative when compared to others.[11]

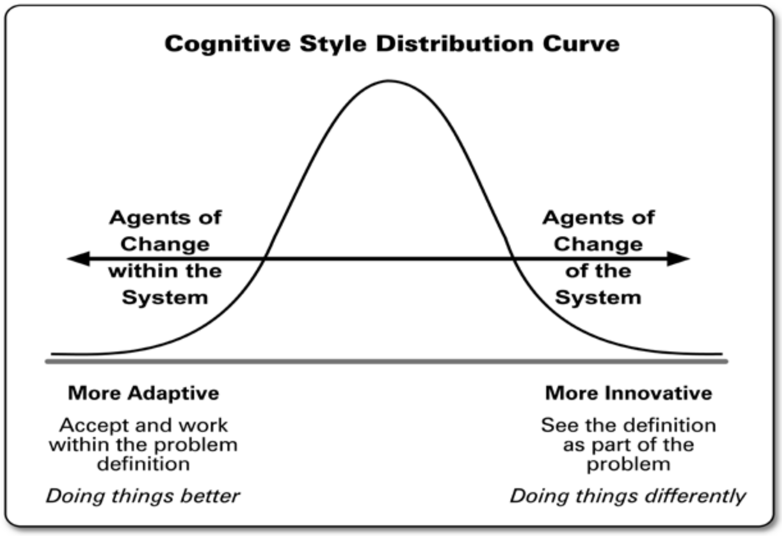


Figure 2. Adaption–Innovation continuum of cognitive style (and a typical distribution)

When it comes to generating and working with ideas, the more adaptive prefer to begin by resolving residual problems that exist within the current, relevant, engineering paradigm. They tend to offer a manageable number of novel ideas that are more readily seen as relevant, sound, efficient, and safe for immediate use. They are often perceived as organized, prudent, conforming, and dependable, and they can generally expect a higher initial success rate for their ideas due to their more immediate fit within the prevailing "way of doing things". In contrast, the more innovative prefer to search for solutions by bending the boundaries of the current engineering paradigm, or even cutting across several paradigms. They tend to offer a proliferation of novel ideas, some of which may be seen as "revolutionary", and which may also be less likely to succeed upon their introduction due to their less obvious fit within the current system. The more innovative are often perceived as unsound, undisciplined, impractical, and perhaps even shocking by their more adaptive counterparts.[11]

3. Experiment Design

With all this theoretical background in mind, we were lead to wonder whether concept maps could be used to visualize variations in cognitive style (i.e., preference for structure). In particular, we posed the following general research questions:

- Are differences in cognitive style discernible through concept mapping?
- If so, which map metrics will correlate with cognitive style?

To investigate these questions, we designed an experiment to explore possible relationships between cognitive style and concept map structure by testing for correlations that would lead to a rejection of the following null hypothesis:

H0: Concept map structure will vary randomly with respect to (students') cognitive style.

3.1 Data Collection

The subjects participating in the study included 77 undergraduate engineering students and 51 graduate engineering students at The Pennsylvania State University. The undergraduates were enrolled in an introductory engineering design course and the graduate students were enrolled in a systems engineering core course. The subjects voluntarily participated in the study during class time. The KAI inventory was administered early in the course to measure the students' cognitive styles; personal feedback on their KAI results was also provided through short workshop-style sessions. Following the administration of the KAI, the subjects were instructed to complete a "common knowledge" concept map by hand on two separate occasions; each map took about 30 minutes to complete. The graduate students constructed "common knowledge" maps based on *moving to a new location*, while the undergraduate concept maps focused on a *college checklist*.

In general, concept maps can be constructed as *open maps* or *closed maps*. In an open map, an individual constructs the map from self-identified concepts, while a closed map is constructed from a predetermined list of concepts provided by someone else. Open maps tend to be more diverse, since the constructor of the map is free to choose his/her own concepts. The challenge of using open maps is that map analysis becomes much more complex. The limitation of a closed map is that the map maker is restricted to certain concepts, with the balancing advantage of easier scoring. We utilized elements from both the open and closed approaches to concept mapping by providing the subjects with a list of concepts related to the designated topic, which they were then free to modify in any way they chose (i.e., adapt, add to, or subtract from).

3.2 Data Analysis

Each map was evaluated by two judges, with discussions occurring as needed to arrive at a consensual rating for each map metric. As described in Section 2, the following *traditional map metrics* were assessed:

- Number of concepts (total)
- Number of concepts from the given list
- Number of concepts added to the list
- Number of concepts unused (from the list)
- Number of links
- Map density (see Eqn. 1)
- Map complexity (see Eqn. 2)

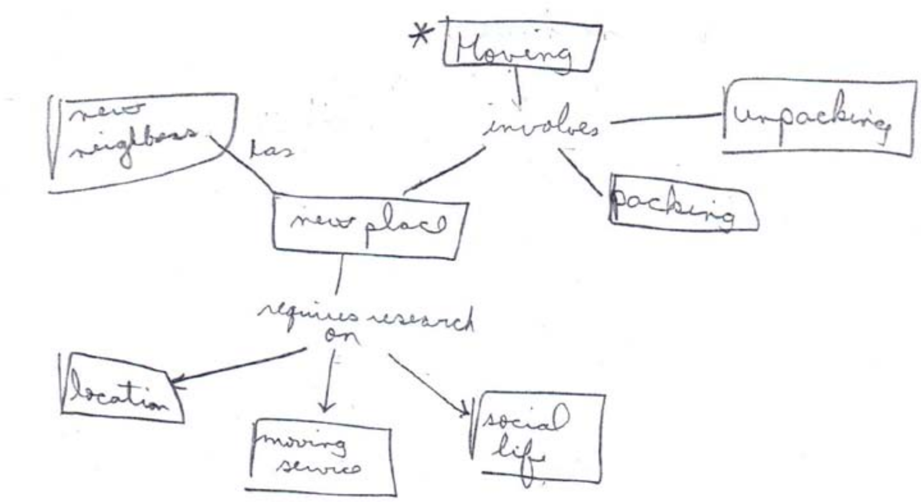
In addition, the following *holistic map metrics* were assessed:

- Dominant map structure (linear, circular, hub/spoke, tree, network)
- Number of hierarchies
- Highest level of hierarchy
- Number of cross-links

An example concept map (from the graduate sample) is provided below, along with the original mapping task instructions and the evaluated map metrics.

Concept Mapping Task—Moving to a New Location: Use the terms below to create a concept map about moving to a new location. Assume you just took a new job and you need to find a place to live; you should also assume you have a partner, a pet, and a child. You can add and delete terms from the list below in creating your map; don't forget to label the links between concepts.

1. Location
2. Work
3. Packing
4. Social Life
5. Unpacking
6. Moving Service
7. House
8. Utilities
9. Transportation
10. Neighbors
11. Services
12. Stores



Assessed *traditional map metrics* of the example map above:

- Number of concepts (total) = 8
- Number of concepts from the given list = 6
- Number of concepts added to the list = 2
- Number of concepts unused (from the list) = 6
- Number of links = 7
- Map density (see Eqn. 1) = 0.125
- Map complexity (see Eqn. 2) = 0.88

Assessed *holistic map metrics* of the example map above:

- Dominant map structure (linear, circular, hub/spoke, tree, network) = Hub/Spoke
- Number of hierarchies = 3
- Highest level of hierarchy = 2
- Number of cross-links = 0

Once the map metrics were determined for all of the maps, we used Minitab to investigate the distributions of the results, as well as possible correlations between them.

4. Results

4.1 Cognitive Style Diversity of the Student Samples

As previously mentioned, we had two sets of subjects: graduate students and undergraduate students (all in engineering). Shown in Figure 3 is the KAI score distribution for the 51 graduate student subjects superimposed on a normal distribution around the same mean. The KAI scores of this sample ranged widely from 61 to 134, which is similar to ranges reported elsewhere for engineers[6]; the individual just-noticeable-difference (JND) for KAI is 10 points.[8,11] The mean of 96.24 for this group was close to the KAI general population mean of 95±(0.5).[11]

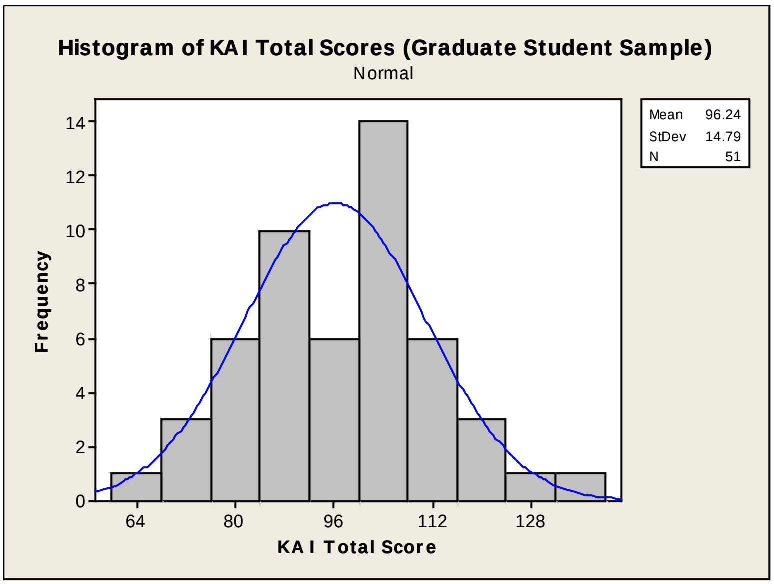


Figure 3. Graduate student KAI distribution

The KAI results for the undergraduate sample are presented in Figures 4 and 5 (superimposed on normal distributions around the same means). As noted previously, the subjects completed their "common knowledge" concept maps twice. In the case of the graduate sample, all students were present on both occasions, so their KAI distribution is presented once (Figure 3). For the undergraduate sample, however, some students were available for only one round of mapping or the other; therefore, we report the two sets of undergraduate KAI results separately.

Figure 4 shows the KAI distribution for the 71 undergraduate students who completed the first round of the college checklist concept map. Once again, the KAI total scores ranged widely (from 62 to 128) with a mean of 95.11. Figure 5 shows the KAI distribution for the 77 undergraduate students who completed the second round of the college checklist concept map. Their KAI total scores ranged from 62 to 128 with a mean of 94.53. From these results, it seems clear that a wide range of cognitive style diversity is present among engineering students at different levels, even with moderate sample sizes.

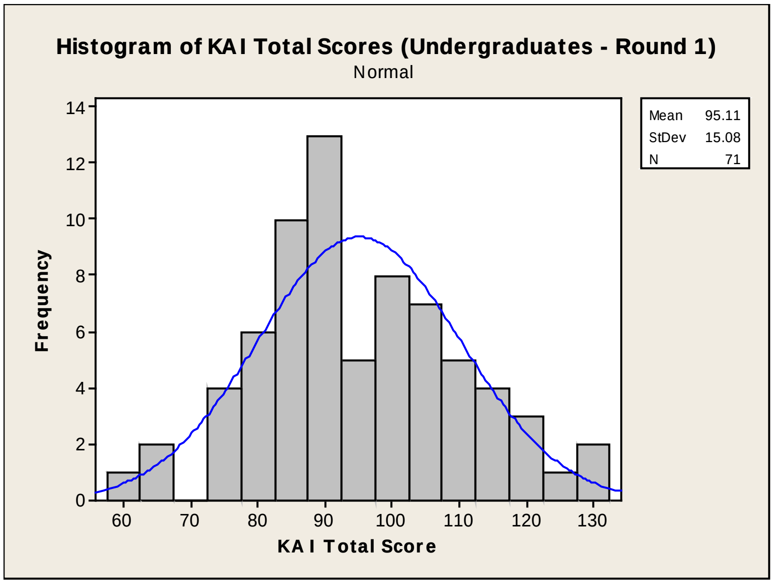


Figure 4. Undergraduate student KAI distribution (first set of common knowledge maps)

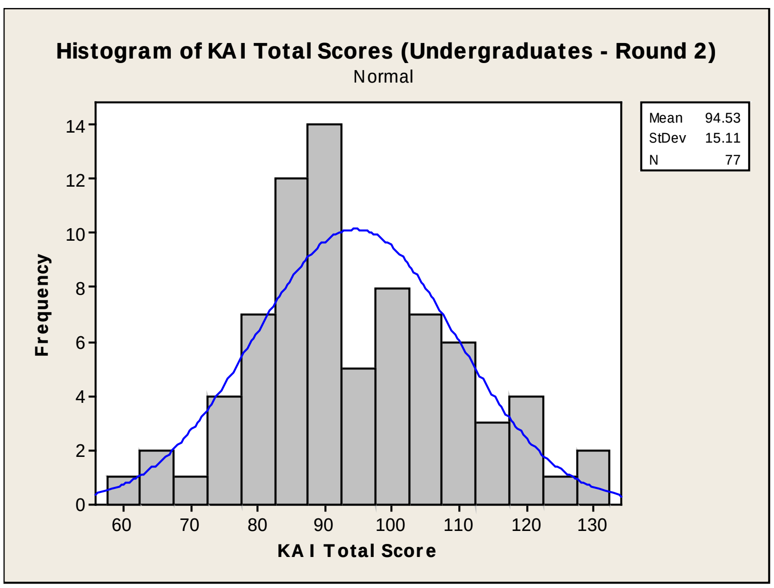


Figure 5. Undergraduate student KAI distribution (second set of common knowledge maps)

4.2 Statistical Analyses and Discussion

4.2.1 Graduate Student Sample

Within the graduate student sample (N = 51), two statistically significant relationships were uncovered through our analysis of the *traditional map metrics*. First, a linear regression analysis (shown in Figure 6) for the total number of concepts versus the KAI total score revealed a correlation of r = 0.36 (p = 0.010), with 11% of the variation in total concepts accounted for by the regression model. This result indicates that when *KAI total score* increases, the *total number of concepts* also tends to increase (although no causality is assumed).

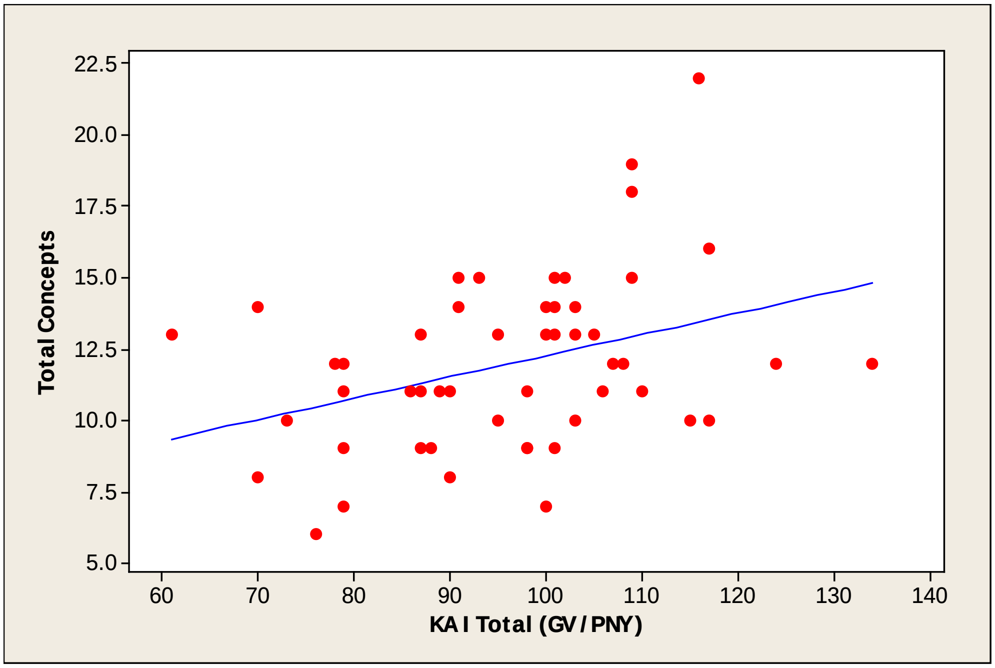


Figure 6. Total concepts regression analysis

In addition, a linear regression analysis for map density versus KAI total score (shown in Figure 7) revealed a correlation of $r = -0.34$ ($p = 0.014$), with 10% of the variation in map density accounted for by the regression model. Here, the result indicates that when *KAI total score* increases, *map density* tends to decrease (again, no causality it assumed).

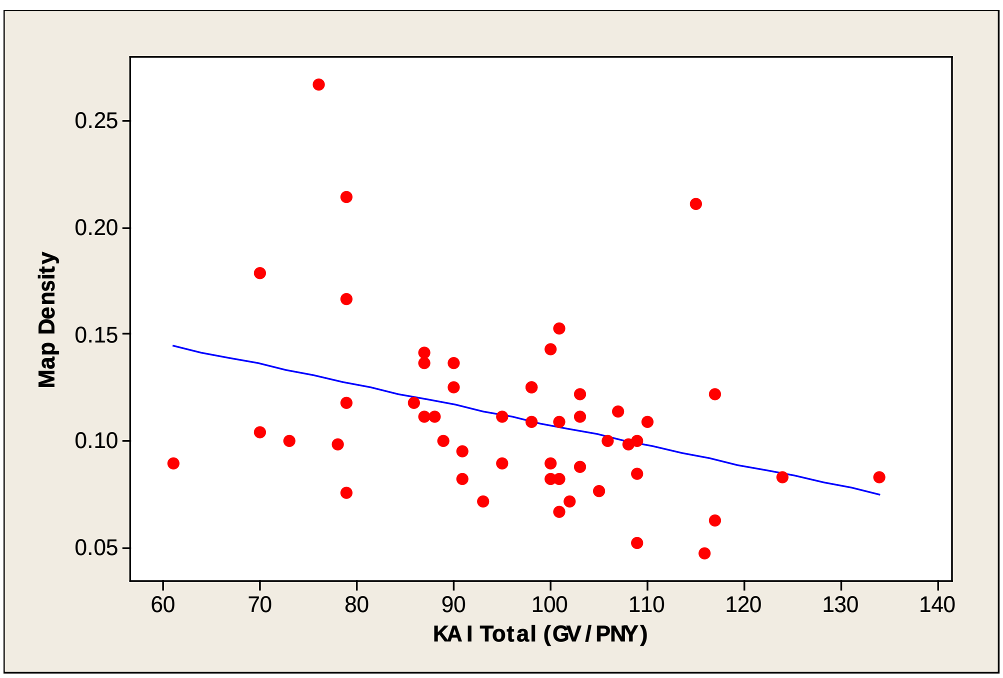


Figure 7. Map density regression analysis

From an A–I perspective, these results make sense. As previously explained, a more innovative person tends to offer more ideas when compared to a more adaptive counterpart (assuming level is equal—no matter how high or low); the more innovative ideas may not all be relevant, but the innovative tendency is to proliferate, leading to an increasing trend in total concepts as KAI score increases. Our expectations of the impact of style diversity appear to be reflected in the map density trend as well (recall Eqn. 1). As the number of concepts increases, the density decreases; our findings here may also imply, however, that the concepts presented by the more innovative are not related or integrated as well as those used by the more adaptive.

In terms of the *holistic map metrics*, none of these proved to be significantly correlated with cognitive style for this sample. However, one of the holistic metrics (*dominant map structure*) did lead to some interesting results, as shown in Figure 8. There, we can see that three different patterns (Hub/Spoke, Tree, and Network) were utilized by individuals across the KAI spectrum.

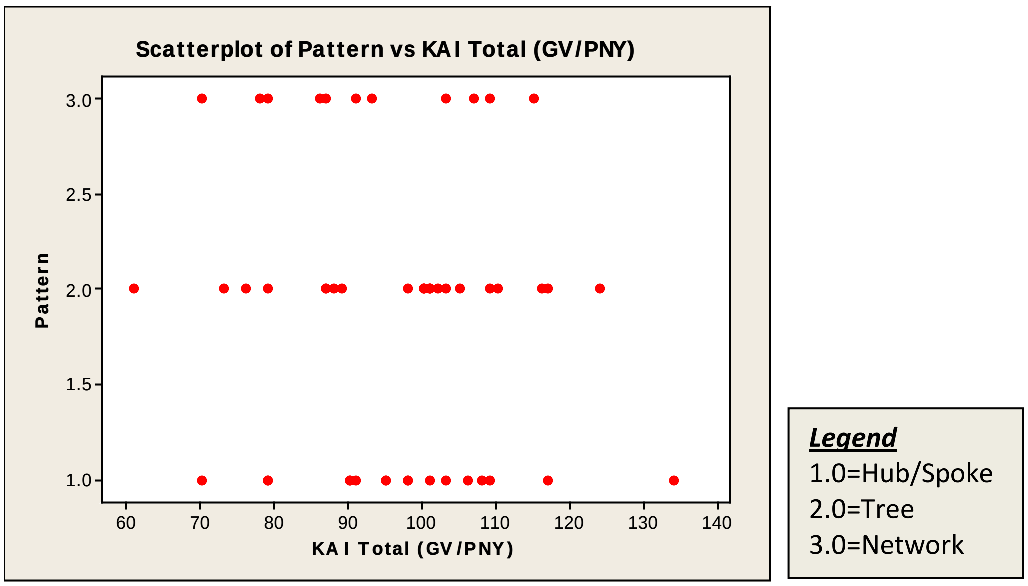


Figure 8. Dominant map structure vs. KAI total score

4.2.2 Undergraduate Student Samples

Within the first undergraduate student sample (first round, $N = 71$), curiously, no statistically significant relationships were found. We are inclined to believe (albeit without concrete proof) that the assignment was not fully understood by these first-year subjects so early in the semester. As a result, we gave them a few more general instructions regarding concept mapping and had them redo the maps later in the course. In the second undergraduate sample (second round, $N = 77$), three statistically significant relationships were uncovered through our analysis of the *traditional map metrics*. First, similar to the graduate sample, a linear regression analysis for the total number of concepts vs. the KAI total score (shown in Figure 9) revealed a correlation of $r = 0.317$ ($p = 0.005$). This result indicates that when *KAI total score* increases, the *total number of concepts* also tends to increase (although no causality is assumed).

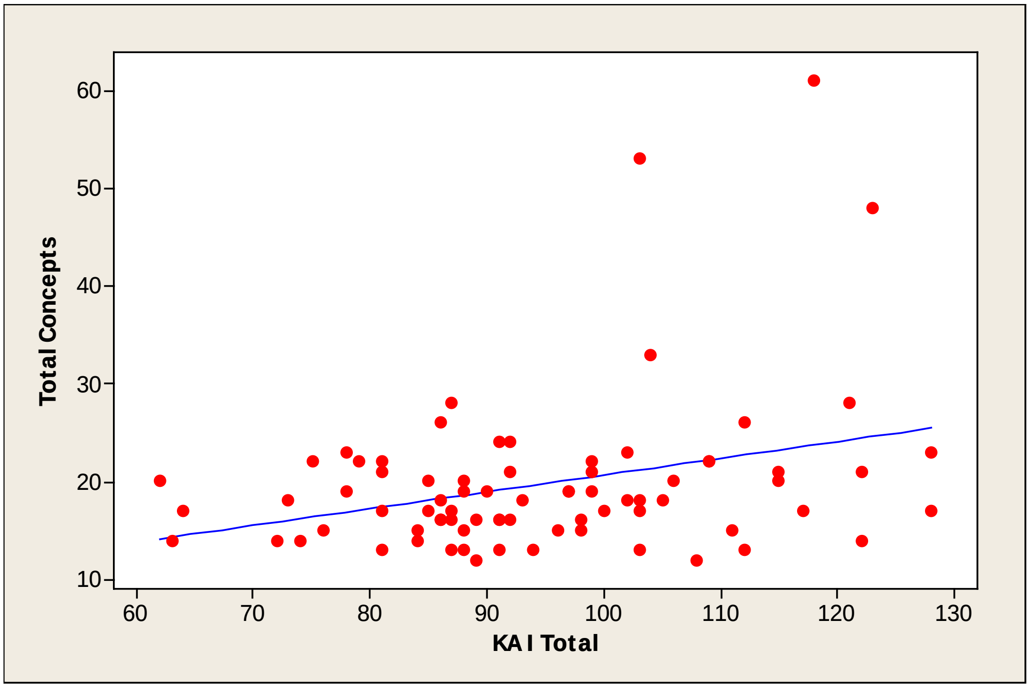


Figure 9. Total concepts regression analysis

As shown in Figure 10, map density was significant at the 10% level with a correlation of $r = -0.222$ ($p = 0.053$). Here, the result indicates (with 90% confidence) that when *KAI total score* increases, *map density* tends to decrease (again, no causality it assumed).

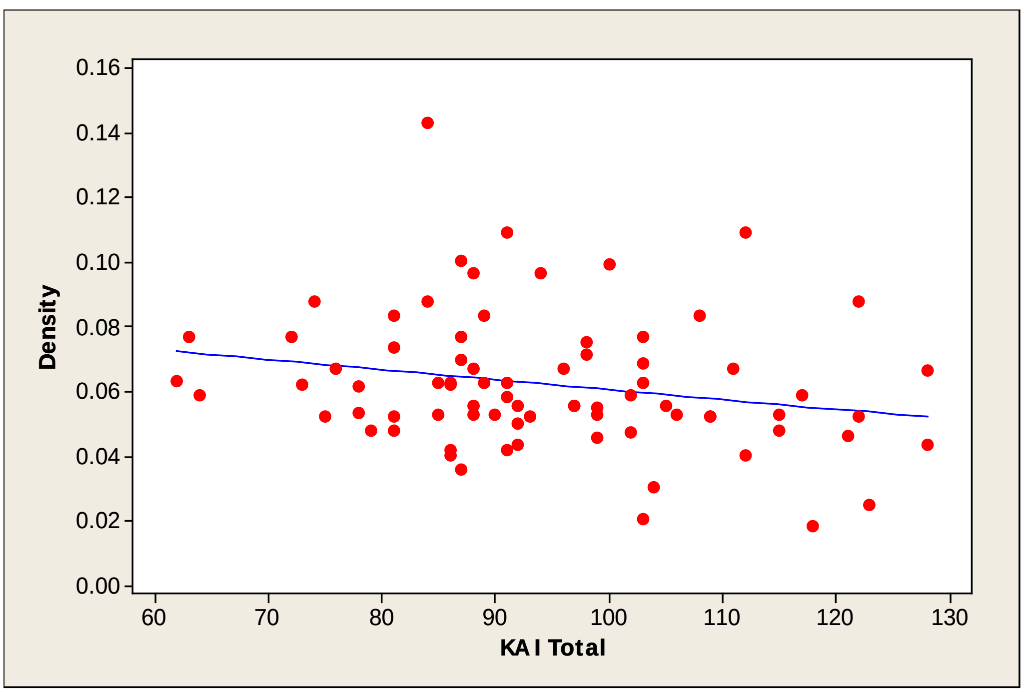


Figure 10. Map density regression analysis

In addition, a linear regression analysis for map links versus KAI total score (shown in Figure 11) revealed a correlation of $r = 0.293$ ($p = 0.010$). Here, the result indicates that when *KAI total score* increases, *the number of links* tends to increase as well (no causality is assumed).

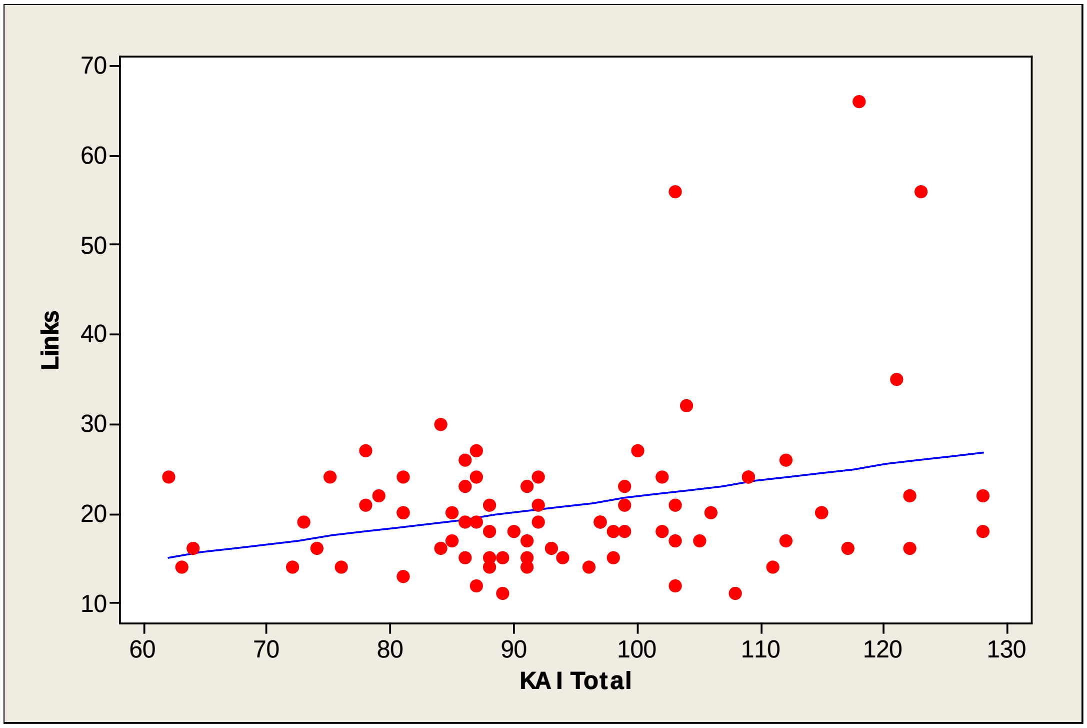


Figure 11. Map links regression analysis

From an A–I perspective, these results make sense. The argument given for the graduate student sample in terms of the increase in concepts with higher KAI score should hold here as well. The more innovative person, assuming equal level (e.g., IQ and/or experience), tends to present more ideas when compared to a more adaptive counterpart. The map density relationship was not as strong for the undergraduate sample as in the graduate sample, however. This might be explained by the fact that, in this sample set, the number of links increased with the KAI score, explaining the difference in density results. Going back to the density equation (Eqn. 1), increasing links causes an increase in density. Increased links coupled with an increased number of concepts caused the density variation to be slightly less than significant. A possible explanation is that the total KAI scores of this sample were slightly more adaptive than the graduate sample, possibly explaining the significant increase in links (more integration of concepts).

As previously discussed, some of the metrics we analyzed were *holistic* by nature, none of which proved to be statistically significant for this sample. However, again, one holistic metric was still interesting (i.e., *dominant map structure*). Figure 12 shows that several different patterns were utilized across the KAI spectrum for the first undergraduate sample, whereas Figure 13 shows that only the tree and hub/spoke patterns were utilized for the second sample, which may be a consequence of the additional concept mapping instruction.

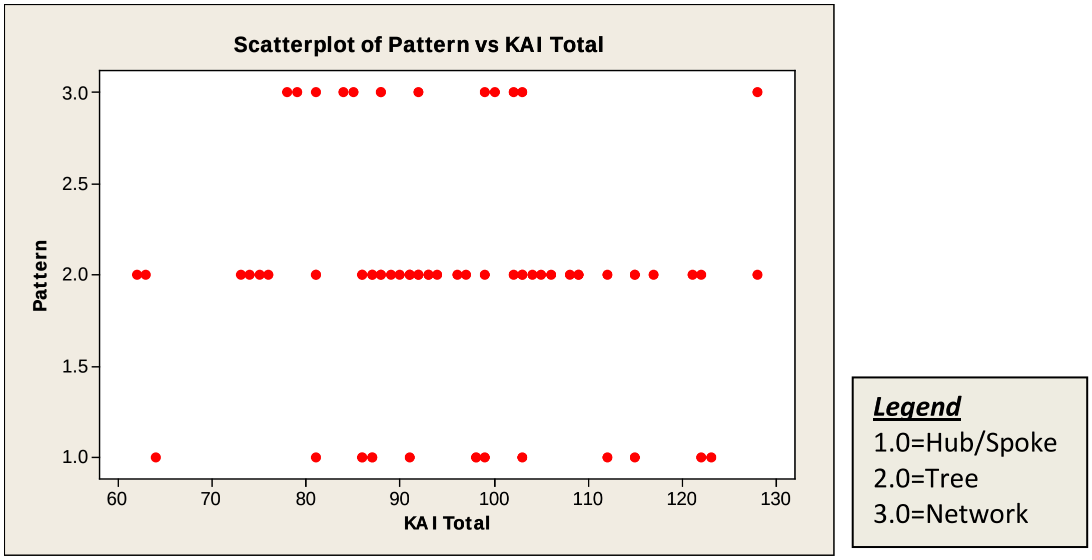


Figure 12. Dominant map structure vs. KAI total score (Undergraduate Round 1)

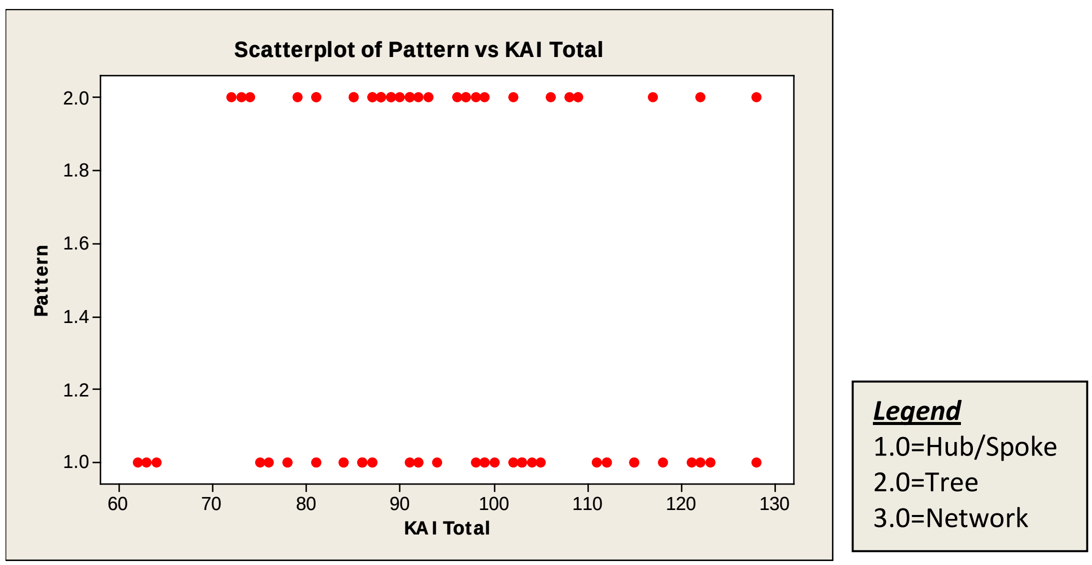


Figure 13. Dominant map structure vs. KAI total score (Undergraduate Round 2)

5. Implications for the Engineering Classroom

In pursuing a means to bring systems thinking awareness to introductory engineering design students,[4] concept mapping has been used to help students discover systems thinking abilities in their everyday lives and in problem solving exercises in class. In addition, concept mapping, as mentioned earlier, is an excellent tool to communicate the understanding of concepts, such as in the early stages of problem solving. If the relationships found in the present exploratory research hold true under further investigation, then our understanding and evaluation of students' concept maps can be improved further.

For example, knowing that a more adaptive student may utilize fewer concepts (but relatively more links) to communicate their understanding of a problem can prevent us from making false assumptions about their level of understanding. In other words, the more adaptive prefer to be more precise in the structure of their maps, which may cause them to utilize fewer concepts in a given time period in comparison to their more innovative counterparts; this does not mean that they know less. On the other hand, a concept map created by a more innovative student may seem overwhelming (particularly to a more adaptive instructor) in terms of the number of concepts used; such a map may need more filtering to analyze what is relevant to the immediate problem—without making the faulty assumption that this student is "messy" or "undisciplined" (again, a misinterpretation of style as level). In either case, our aim is a separation of the effects of cognitive level and cognitive style (as recommended by Jablokow and Kirton[8]) in order to assess each construct more accurately.

These insights can also help engineering instructors improve the effectiveness of the instructions they give their students for concept mapping to meet a particular problem. For example, if a problem requires a high level of detail, an instructor may need to provide different instruction and motivation for different students in order to achieve their desired results, as their students' cognitive styles (if more innovative) may not facilitate the production of detail in their mapping. A similar approach would be required if a problem requires a more "abstract" map from more adaptive students, who may need special reminders (or instruction) to help them produce a "big picture" view versus minute detail. These and similar interventions will require further investigation in future projects, once the relationships between cognitive style and concept mapping uncovered here have been fully explored and validated.

6. Limitations, Conclusions, and Future Work

As with all exploratory studies, there are limitations to our work that will need to be addressed in future studies. In addition to increasing our sample size to confirm the results of this study, we also need to address certain aspects of concept map analysis techniques, in that the analysis is somewhat subjective for some of the holistic scoring metrics. We also need to determine if we have utilized all possible mapping metrics for this type of investigation or if other types of data mining techniques (for example) might be used to uncover important patterns and relationships, such as running a multiple regression analysis on the map data to see how well they predict KAI scores.

When working in a team, cognitive diversity is a reality that needs to be recognized; it can be a positive and enabling attribute if managed well. In this paper, we have uncovered some potentially important effects of cognitive style diversity on concept mapping in the first phase of a larger effort. We will continue to explore the effects of cognitive diversity on concept mapping, as well as the metrics that should be utilized in the analysis of the maps. In addition, we have identified a few directions that seem to indicate the impact of cognitive style on the way in which students structure their ideas (total number of concepts used, map density, and number of links). These factors need to be explored in more depth with additional samples and other course-related mapping topics.

7. References

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