The use of concept mapping as an alternative form of instruction and assessment in a capstone biomedical engineering design course

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Abstract

Grounded in interdisciplinary efforts to improve student learning and professional development in the domain of bioengineering, this paper describes the design, use, and evaluation of an alternative form of instruction and assessment in a yearlong senior biomedical engineering (BME) design course at Vanderbilt University. Specifically, members of the Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center (VaNTH ERC) Assessment and Evaluation Team and the instructor of a yearlong capstone BME design course developed and implemented ways in which concept mapping would (1) promote active student engagement with course material and (2) serve as a framework for helping students integrate new knowledge into existing knowledge. Consistent with our previous work in this area, quantitative analyses of concept maps created by students (n = 51) at the beginning and end of the fall semester showed significant growth in students' conceptual knowledge of the design process. However, early and late maps did not differ in terms of associations among concepts. These findings suggest that while students are acquiring knowledge about design, they do not have a deep understanding of relationships among elements of the design process. As an indication of the extent to which concept maps actively engage students with course material, we are comparing this year's class (i.e., Innovative group) and the previous year's class which received traditional instruction (i.e., Traditional group), in terms of student final exam scores, course evaluations, learning strategy use, intrinsic motivation to learn, and perceptions of the course experience. Findings are discussed in terms of their implications for theoretical understanding of the structure of knowledge, and instructor efforts to enhance students' conceptual understanding of the design process.

Introduction

Theoretical work and empirical evidence shows that learning is not only the acquisition and understanding of concepts but also the construction of meaningful links among concepts.[1,2, 3, 4] Grounded in this perspective, members of the Vanderbilt-Northwestern-Texas-Harvard/MIT Engineering Research Center (VaNTH ERC) Assessment and Evaluation Team and the design course instructor of a yearlong senior biomedical engineering (BME) design course at Vanderbilt University explored the utility of one alternative form of instruction and student assessment, concept mapping.

A concept map looks like a flow chart; however, instead of mapping the linear structure of knowledge, concept maps reflect the psychological or associative structure of knowledge.[5] Consistent with constructivist learning theory and research, concept maps are composed of interrelated elements: nodes, directed lines and labels. Nodes represent concepts. Concepts are "perceived regularities in events or objects, or records of events or objects, designated by a label." [6] For example, 'engineering' and 'experimentation' are concepts. Lines represent relations among concepts. Labels in the lines describe the nature of those relations (e.g., 'leads to') while arrowheads indicate the direction of the relationship. The combination of a pair of concepts and a line constitutes the fundamental unit of a concept map, a proposition. Each proposition is a statement about some object or event in the universe [6] (e.g., 'engineering leads to experimentation'). Figures 1 and 2 provide examples of how concept maps can be structured hierarchically and non-hierarchically, and describe aspects of concept mapping.

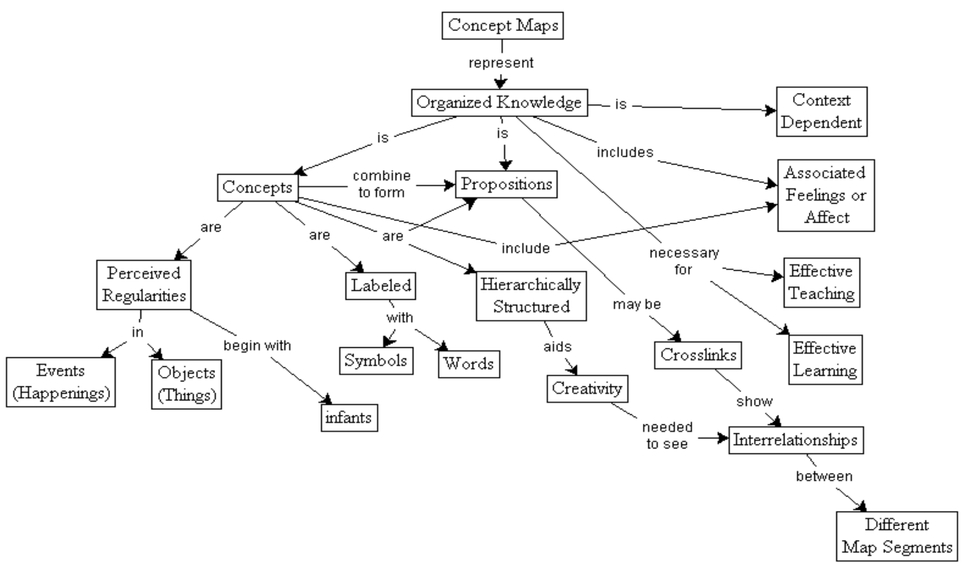

Figure 1. Example of hierarchical concept map (Taken from Novak, 2000).

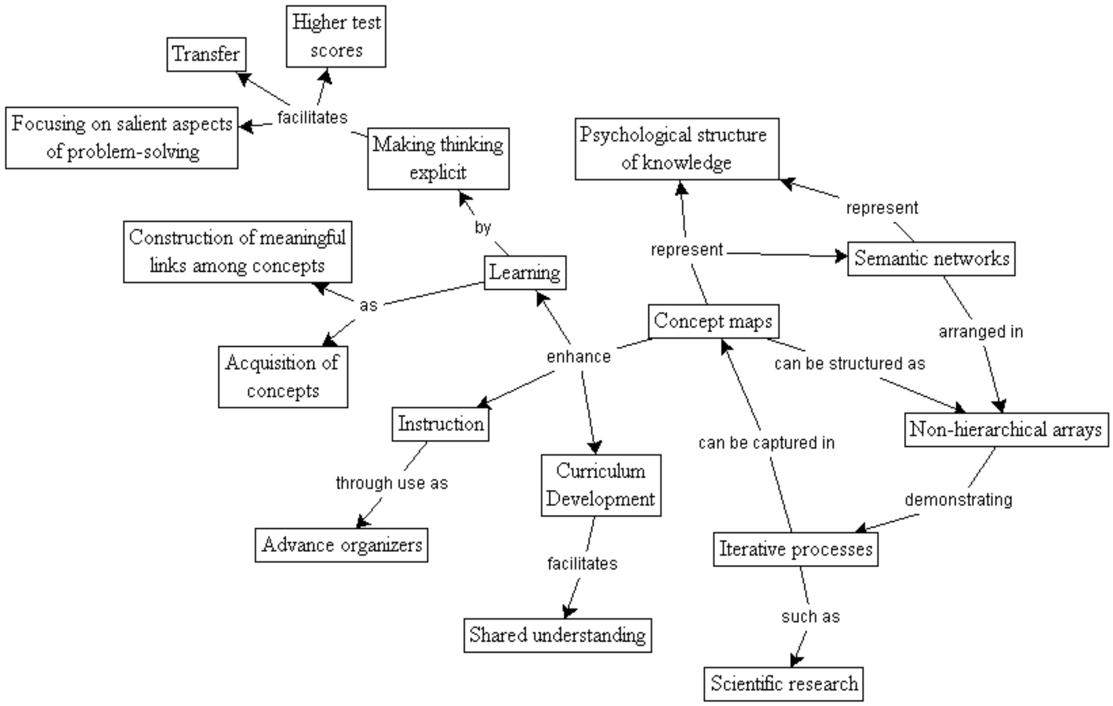

Figure 2. Example of non-hierarchical concept map.

Because use of concept mapping has been associated with the enhancement of numerous student outcomes, including greater focus on salient rather than irrelevant aspects of problem-solving, [7] transfer of problem-solving skills, [8] and better test scores [9,10], we expected the technique to actively engage students with course material and help students integrate new conceptual knowledge into existing knowledge structures. Further, students often enter the classroom with diverse experiences and levels of prior knowledge making it difficult for instructors to know what individual students do and do not know and understand. Unlike traditional forms of assessment (e.g., multiple-choice tests), concept mapping allows instructors the opportunity to observe how extensive and integrated a student's conceptual knowledge is, and, in turn, share their own conceptual understanding with students. Moreover, concept mapping as a form of assessment offers teachers the opportunity to recognize a student's misconceptions, impediments to learning that traditional assessments may not detect. In short, the technique facilitates the achievement of a shared conceptual understanding between teacher and student.

To construe the goal of concept mapping as convergence between students' and teachers' maps, however, is to misunderstand the constructivist origins of the task. Theoretically, the power of concept mapping does not lie in the fact that it trains students to 'think just like the teacher,' but rather in its ability to actively engage students in the material, and portray the process of knowledge transformation as students gain expertise within a domain.[11] For example, studies of students' concept mappings over time have revealed that as conceptual knowledge develops, map vocabulary becomes increasingly precise and concepts become more densely networked.[12, 13, 14]

Concept maps have been used as a learning strategy, an instructional strategy, a strategy for curriculum planning, and a means of student assessment.[15] In this study, we used concept mapping as: (1) a form of student assessment (i.e., a measure of students' conceptual understanding of the design process); (2) a learning strategy (i.e., students created maps as a study guide for their final exam and summarized course readings in concept map form), and (3) a form of instruction (i.e., organizational framework for instructional units).

In the sections that follow, we describe the data we have collected and analyzed to date, methods of evaluation, and preliminary findings. We conclude with a discussion of the potential of concept mapping as a method for capturing and assessing students' conceptual knowledge of the design process, and an instructional technique that helps students integrate new knowledge into existing knowledge structures. We also describe ways in which design instructors might incorporate concept maps into their teaching, and offer suggestions for future research.

Methods

Participants were 51 (18 females, 33 males; 49 seniors, 2 juniors) students enrolled in a yearlong capstone design course at Vanderbilt University. On the first day of class, students completed a brief written survey in which they described their education level, industrial experience, specific interests, etc. The following week, the first author gave students a brief orientation to concept mapping (see Appendix A). Once the orientation was concluded, students received their first homework assignment: Construct a concept map based on the following focus question, "What is your current conceptual understanding of what is involved in the biomedical engineering design process?" Students were given a chance to ask any clarifying questions about the technique.

Shortly before the final exam at the end of the fall semester, students constructed a second map based on this same focus question. Students were allowed, and encouraged, to use this map as a study guide and "final exam cheat sheet" (see Appendix B). At this time, students also completed a brief anonymous survey asking them to indicate their area of interest, and to rate the difficulty of the mapping task in general and in terms of specific aspects of the task on a 5-point scale (e.g., generating concepts vs. labeling links). This survey also asked students if they had prior experience with concept maps and if they would use concept maps as a personal study practice or as a tool for presenting material to others. Students also had space to make any comments.

To assist the class in understanding the use of concept maps as a tool for summarizing course materials and instruction, mid-way through the semester one chapter lecture was given. The chapter covered was on safety, the lecture opened with a concept map showing the general topics of the chapter (6 major concepts), the lecture concluded with a detailed concept map (32 concepts) of the topics covered.

Following this experience, students were asked to generate a concept map summarizing one chapter, of their choice, from the course textbook.[16] To enhance the comprehensiveness of their individual maps, students received feedback from the instructor regarding the quality (e.g., differentiation, integration) of the nodes, lines, and links contained in their chapter summary maps.

In sum, we collected five types of data from students. First, we collected an initial survey of students' school and work experience. This allowed us to control for individual differences in participants' educational and work experience. Second, we collected a baseline map of students' conceptual understanding of the BME design process. Third, we demonstrated how concept maps can provide general and specific overviews of course material, and asked students to summarize course readings in concept map form. Fourth, we collected a second concept map of students' conceptual understanding of the BME design process. Finally, we asked students for their reflections on the difficulty and utility of the Time 2 mapping task. In the next section, we describe how these data were evaluated.

Methods of Evaluation

Each summer that students had spent in school or in research or lab settings was counted. Of the 51 students enrolled in the course, 29 had prior research experience, 27 had prior lab experience, and 32 were enrolled previously in summer school.

Student concept maps at Times 1 and 2 were analyzed for within and between subject differences. Specifically, the course instructor counted the number of nodes and lines in all Time 1 and Time 2 maps. Second, because density or the number of lines per node has been associated with expert knowledge structures,[14] a line:node ratio was calculated by dividing the number of lines by the number of nodes. Finally, using a relational scoring system,[17] the course instructor, blind to the identity of the maps' author, then rated the validity of each map's propositions based on the correctness of the line label. No points were given for an invalid or misconceived link; 1 point was given for a partially valid, general or imprecise link; and 2 points were given for a valid, precise, and clearly stated link.

Student evaluations of the concept mapping task asked students to: (1) rate the overall level of difficulty of the mapping task on a 5-point scale (1 = not at all difficult, 5 = very difficult); (2) rank order the difficulty of specific aspects of creating a concept map (i.e., generating a list of concepts, connecting concepts, labeling links between concepts); (3) indicate whether they had previous experience with concept maps; and (4) indicate whether they found the mapping task useful as a study technique or tool for conveying information to others.

Results & Discussion

At Time 1, student concept maps averaged 16 nodes (M = 15.60, SD = 4.44, range = 10-34) and 18 lines (M = 18.32, SD = 5.41, range = 11-37). The average line:node ratio was 1.19 (SD = .29). The average validity rating of map propositions was .89 (SD = .11, range = 0-2). Consistent with our previous work[13] at Time 2, student maps contained a greater number of nodes (M = 32.51, SD = 12.91, range = 13-63) and lines (M = 37.66, SD = 13.56, range 17-73). The average Time 2 line:node ratio was 1.21 (SD = .33). The average validity rating of Time 2 map propositions was .88 (SD = .17, range = 0 to 2). Paired sample t-tests showed statistically significant differences in Time 1 and Time 2 maps in terms of nodes (Mean difference = 17.20, SD = 12.38, t [45] = 9.42, $p < .00$) and lines (Mean difference =19.04, SD = 13.02, t [45] = 9.92, $p < .00$). The line:node and validity ratings at Times 1 and 2 did not differ. These data are summarized in Table 1.

Table 1. Mean number of nodes, lines, and line:node and validity ratios in student maps at the beginning (Time 1) and end (Time 2) of the fall semester.

	Nodes	Lines	Line:Node	Validity
Time 1	15.60	18.32	1.19	.89
Time 2	32.51	37.66	1.21	.88

Significant increases in the number of lines and nodes in student maps across the first semester suggest that students have gained conceptual knowledge. However, lack of significant differences in the validity of map propositions suggests that students have not necessarily gained a deeper understanding of associations among concepts pertinent to the design process. Grounded in our prior work,[18] we expect that once students begin to apply their conceptual knowledge to the actual design of a device (the focus of the spring semester of the course), their maps will not only contain more concepts, but more valid propositions, more precise vocabulary, and greater integration (i.e., higher line:node ratios).

Links between concept map data and the number of summers students had spent in school, or in industrial or laboratory settings were examined (industrial experience, M = 1.34, SD = .61; lab experience, M = 1.37, SD = .74; summer school, M = 1.59, SD = .80). No significant relationships were found at Time 1; however, at Time 2, a negative correlation was found between the validity of map propositions and number of summers spent in school ($r = -.47$, $p < .01$). At present, we are examining maps in terms of individual differences (i.e., work and educational experience) as well as qualitative differences in student maps over time.

Preliminary analyses of chapter summary maps indicate that most of the class can create logical structures, but that some students are far more comprehensive in their coverage than others. Chapter maps constructed by this year's class will be revised by the instructor and used as teaching media (i.e., PowerPoint) in next year's capstone course. Future requests for student summaries of course readings might give students a list of concepts from the material and then ask them to array those particular concepts. This method might provide a better standard for comparing students' knowledge structures and extent of integration.

Analyses of surveys completed along with Time 2 maps showed that students found the task moderately difficult (M =2.39, SD = .97, range = 1 to 4) and no one aspect of map construction appeared most difficult. With regard to prior experience with concept maps, 4 of the 51 students had used the technique. Of the 39 students who completed the survey, 28 found the technique useful for presenting material to others while only 11 found it useful as a personal study practice. Qualitative comments from students about the mapping task included positive perceptions and suggestions for future use (e.g., "I think concept mapping was helpful. Maybe tips for generating a list of concepts would be helpful"), as well as less positive comments (e.g., "I'm not a visual person so I don't really find them helpful. I prefer outlines and step-by-step processes").

To further assess the effectiveness of innovations in the course, we are seeking information from three additional sources. First, student scores on the final exam at the end of the first semester are being compared to a control group (i.e., students who were enrolled in the course the previous year with the same instructor, but who received traditional forms of instruction). Second, student course evaluations completed by the Innovative (i.e., this year's class) and Traditional (i.e., the previous year's class) groups at the end of the fall semester are being compared. Evaluations contain quantitative ratings on various aspects of instruction and qualitative comments about the course and the instructor. Third, at the end of the spring semester, students will complete a second course evaluation, and self-report questionnaires assessing their motivation, learning strategy use, and perceptions of their course experience. These data will also compare Innovative and Traditional groups. We expect these data to enhance understanding of whether homework assignments and changes in instruction translated into greater student engagement, more coherent understanding, and thus higher academic performance. In general, we expect to find that relative to the control group, students in this year's class will perform better on exams, give more positive course evaluations, and have greater intrinsic motivation for their assignments.

Limitations of this work include issues surrounding methods of map construction and scoring.[18, 19] For example, when students freely generate maps, they can construct them in hierarchical and non-hierarchical arrays. Lack of structural consistency complicates interpretation of maps across students. Further, while several methods exist for scoring what is present in student maps, there is no system for evaluating maps based on what is missing. Additionally, to date, only one rater has scored all maps. To enhance the reliability of these findings, at least two raters will score all maps and an inter-rater reliability will be calculated. These ratings will be conducted at the conclusion of the study, or the end of the spring semester. At this time, we will collect a third and final map based on the same focus question (i.e., What is your current conceptual understanding of what is involved in the BME design process?) to track changes in students' knowledge structures across the year. Finally, careful assessment of student maps requires time. One of our primary objectives is to devise an efficient means to evaluate the content of student maps and obtain a listing of what is missing. In the absence of such a tool, future work might ask students to construct a map with a predetermined list of concepts. Such a manipulation may enhance our ability to more quickly assess the validity of map propositions and failures to link associated concepts, and thus provide timely, valuable feedback to the instructor and students about students' conceptual development.

(This work was supported primarily by the Engineering Research Centers Program of the National Science Foundation under Award Number EEC9876363. The authors extend many thanks to the students and faculty who graciously gave their time.)

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Appendix A
How to build a concept map

1. Think about the focus question you have been given, and identify 10 to 20 of the most pertinent concepts (single words or three words at most). List these concepts on a piece of paper, and then write each one on a separate post-it note.

2. There are two options for arranging your post-it notes.
   - Your map can be structured hierarchically by placing the most inclusive, most general concept(s) at the top and less important concepts at the bottom (see Figure 1).
   - Your map may also be constructed as a non-hierarchical network. In this case, there is no superordinate concept; the map is structured like a web (see Figure 2).

3. Now begin arranging your post-it notes.
   - If your map is hierarchical, place less important concepts under the more general concepts. In other words, if someone else read the map they would move "top down" from the most to the least important ideas.
   - If your map is non-hierarchical, array the concepts according to their degree of relatedness. The map would read in a non-linear fashion.

Note: Sometimes people change their minds about the map's overall structure as they begin arranging the concepts. Whatever structure you prefer is fine. There are not right or wrong constructions.

4. Flip over the piece of paper on which you wrote your list of concepts and draw your array of post-it notes on it.

5. Think about which concepts are related. Connect related concepts with lines.

6. Label the lines with one or a few linking words. Linking words should define the relationship between the two concepts. For example, "involves" and "leads to" are linking words.

7. Each pair of linked concepts should read like a sentence. For example, the concepts "engineering" and "experimentation" could be linked by the words "leads to." This creates the statement "engineering leads to experimentation."

8. Add arrowheads to the lines between the concepts to indicate the direction of the relationship. Depending on the nature of the concepts' relationship, lines can have single or double arrowheads. For

example, the proposition "engineering leads to experimentation" would have a single-headed connecting arrow between engineering and experimentation. Other concepts may be mutually influential (bi-directional). Use double-headed arrows to depict this relationship.

Appendix B

Concept Mapping Assignment, 2 parts

1. By 10/31/2002 develop and turn in a concept map for any chapter other than Chapter 11, similar in form to that shown in class by Dr. King on Chapter 11. (5 Points.)

2. By 11/5/2002 develop and turn in a concept map that you have developed due to the request: "What is your current conceptual understanding of what is involved in the BME design process?" Please limit this map to a single sheet. This map will be Xeroxed by Dr. King and given back to you along with your first map in this course. These two maps will be given back to you on the final exam day, they are meant to be both study and evaluation guides. (10 points)

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