Board 49: Enhancing Student Active Learning via Concept Mapping in an Undergraduate Engineering Course

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Introduction

Effective knowledge organization plays a critical role for students to learn Science, Technology, Engineering and Mathematics (STEM) subjects [1], [2]. Well-organized knowledge not only helps students develop a deep understanding, but it also helps students learn new knowledge. Among a variety of approaches and techniques developed for knowledge organization, such as indexing, classification, and various digital databases, concept mapping has received increasing attention in recent years in STEM education [3]-[5]. Concept mapping is a visual technique for knowledge organization, representation, and elicitation [6]. In a concept map, concepts are often arranged based on their hierarchical relationships, so that students can visualize relationships between relevant concepts. Research has shown that concept mapping improves students' understanding of concepts [7], [8] and can also be used as an assessment tool to diagnose students' learning problems and ways of thinking [9], [10].

In the present study, the technique of concept mapping was implemented in a second-year undergraduate engineering course entitled Engineering Dynamics. This course is a required, high-enrollment, high-impact course in many engineering programs, such as mechanical, civil, and aerospace engineering. The course covers numerous fundamental concepts, such as force, acceleration, work, energy, impulse, and momentum [11]. Therefore, student performance in this course is often of significant concern. In the recent standard Fundamentals of Engineering examination in the U.S., the national average score on the dynamics exam was only 53% [12].

In the traditional approach to concept mapping in Engineering Dynamics, the instructor constructs concept maps for students and then presents the map in lectures [13]. This traditional approach is passive learning because students simply view the instructor's concept map and listen to his/her explanations in class. In the present study, students, rather than the instructor, construct their own concept maps in order to promote active learning. This executive summary describes how concept mapping was implemented in an Engineering Dynamics course and the results of a questionnaire survey to find out student experiences with concept mapping.

Active learning via concept mapping

Engineering dynamics deals with the motion of objects and the relationship between forces and motion. At the beginning of a 16-week semester, students learned how to use a free computer software program, IHMC Cmap Tools, to draw a concept map. This software was particularly developed for concept mapping and can be downloaded online at http://cmap.ihmc.us. With this software, students could easily create, edit, and modify digital concept maps.

Throughout the 16-week semester, students learned eight topics, corresponding to eight textbook chapters, in Engineering Dynamics [14]. Four topics were on particle dynamics, and the other four on rigid-body dynamics. After the teaching and learning of a topic was completed, each student developed a concept map for the topic. Students were provided three to five days to

construct their concept maps after class. At the end of the semester, each student had created a total of eight concept maps covering eight topics.

Questionnaire survey

At the end of the semester, a questionnaire survey was administrated to find out student experiences with concept mapping. A total of 92 students who took Engineering Dynamics in the semester participated in the survey. These students were primarily from two departments at the author's institution: Mechanical and Aerospace Engineering (MAE) and Civil and Environment Engineering (CEE) departments. The survey included both Likert-type and open-response items. The following paragraphs describe three survey items:

Item #1: Please rate your overall experience with developing your own concept maps: A) Highly negative, B) Negative, C) Neutral, D) Positive, E) Highly positive

Item #2: Overall, the concept maps helped improve your conceptual understanding of dynamics concepts, laws, and principles as well as their relationships: A) Strongly disagree, B) Disagree, C) Neutral, D) Agree, E) Strongly agree.

Item #3: Please describe in detail how the concept maps helped, or did not help, with your conceptual understanding of dynamics concepts, laws, and principles as well as their relationships.

Results and discussions

Student-constructed concept maps

Figure 1 shows the excerpt of a student-constructed concept map on the topic of Kinematics of a Particle. The map correctly shows that kinematics deals with both rectilinear kinematics and curvilinear kinematics. For rectilinear kinematics, the map shows three fundamental quantities and four important equations. Most importantly, it shows how to deal with continuous motion and erratic motion. The map includes a note (in the middle of Figure 1) on different coordinate systems. Although this note is not explicitly connected with any other concepts on the map, it reflects the student's correct understanding of coordinate systems.

Figure 2 shows the excerpt of a student-constructed concept map on the topic of Planar Kinematics of a Rigid Body. The map clearly shows two methods used in analyzing general plane motion of a rigid body, including absolute motion analysis and relative motion analysis. The map also includes notes (at the right bottom corner of Figure 2) about the instantaneous center of zero velocity, a critical concept used in the analysis of general plane motion.

Survey results

Tables 1 and 2 show student responses to survey items #1 and #2, respectively. 61% of the students rated their experiences with concept mapping as "positive" or "highly positively," and 54% of the students "agree" or "strongly agree" concept maps helped improve their conceptual understanding of dynamics concepts, laws, and principles, as well as their relationships.

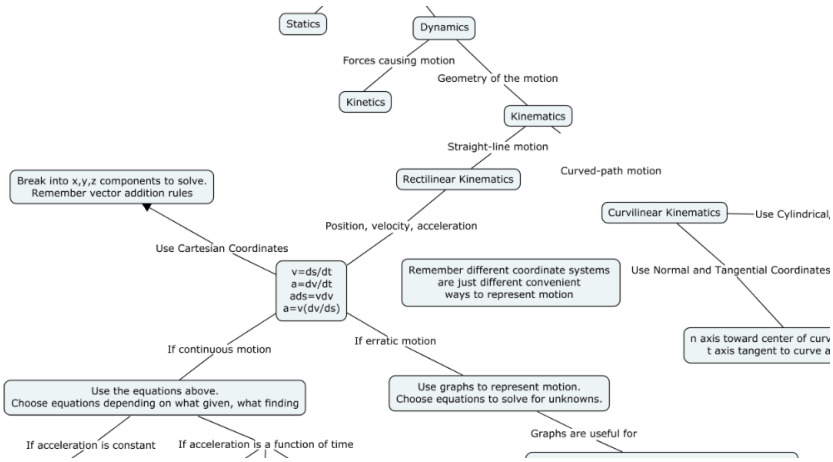

Figure 1. The excerpt of a student-constructed concept map: example 1

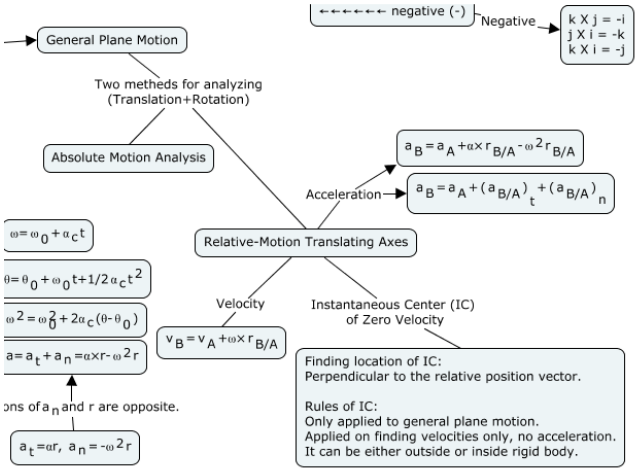

Figure 2. The excerpt of a student-constructed concept map: example 2

Table 1. Student responses to survey item #1

Answer choice	Highly negative	Negative	Neutral	Positive	Highly positive
No. of students	1	13	22	52	4
% of students	1%	14%	24%	57%	4%

Table 2. Student responses to survey item #2

Answer choice	Strongly disagree	Disagree	Neutral	Agree	Strongly agree
No. of students	5	16	21	47	3
% of students	5%	17%	23%	51%	3%

Figure 3 further shows how student experiences with concept mapping related to their final exam scores. The final exam was comprehensive, covering all topics students had learned in the

course. It required students to apply learnings to solve a variety of engineering dynamics problems. Because the number of students who rated their experiences as "highly positive" or "highly negative" was small, those students were not included in Figure 3.

As seen from Figure 3, on average, students who indicated "positive" experiences with concept mapping scored 4% higher on the final exam than the class average. In contrast, students who indicated "negative" experiences scored 9% lower on the final exam than the class average.

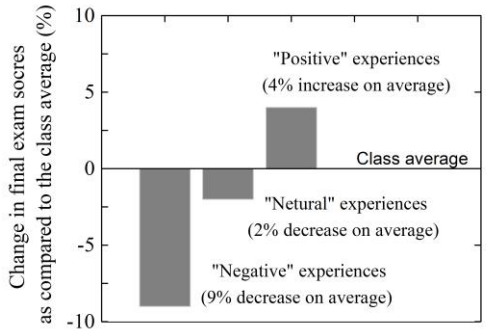

Figure 3. Student experiences vs. final exam scores

The following paragraphs list representative student responses to survey item #3:

- "As I made the maps, I always related the equations to the concept, and even though in class we would talk about it, when I would have that straight line from a concept to an equation it really helped me see the connection."
- "Creating a visual map helped see how everything relates. Knowing which equations go with what topic and how some concepts relate to others."
- "The concept maps were a good review of the material from each chapter. Making the maps gave me the opportunity to review the material I had learned and check my understanding of each concept."
- "The concept maps were a huge help in keeping track of all the principles we learn. It helped organize my materials and what tools I had and where these tools could apply. In addition it helped me step back and see why it was important to keep all of these things in perspective and the importance of the concepts and why I needed to understand them."

Conclusions

This paper has described how concept mapping was implemented to promote active learning in Engineering Dynamics. The results of the questionnaire survey show that overall, concept mapping had a positive impact on student learning. The future work will focus on the study of how concept mapping affects students' long-term knowledge retention.

Acknowledgements

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References

[1] M. E. Serna, O. S. Bachiller and A. A. Serna, "Knowledge meaning and management in requirements engineering," *International Journal of Information Management*, vol. 37, pp. 155-161, Jun. 2017.

[2] C. McMahon, A. Lowe and S. Culley, "Knowledge management in engineering design: personalization and codification," *Journal of Engineering Design*, vol. 15, pp. 307-325, Jan. 2007.

[3] S. R. Rosas and J. W. Ridings, "The use of concept mapping in measurement development and evaluation: Application and future directions," *Evaluation and Program Planning*, vol. 60, pp. 265-276, Feb. 2017.

[4] J. P. Donnelly, "A systematic review of concept mapping dissertations," *Evaluation and Program Planning*, vol. 60, pp. 186-193, Feb. 2017.

[5] G. J. Hwang, F. R. Kuo, N. S. Chen and H. J. Ho, "Effects of an integrated concept mapping and web-based problem-solving approach on students' learning achievements, perceptions and cognitive loads," Computers & Education, vol. 71, pp. 77-86, Feb. 2014.

[6] J. D. Novak and D. B. Gowin, *Learning How to Learn*. New York, NY: Cambridge University Press, 1984.

[7] K. M. Hamza and P. O. Wickman, "Student engagement with artefacts and scientific ideas in a laboratory and a concept-mapping activity," *International Journal of Science Education*, vol. 35, pp. 2254-2277, Jul. 2013.

[8] H. Wang, I. Huang and G. Hwang, "Effects of a question prompt-based concept mapping approach on students' learning achievements, attitudes and 5C competences in project-based computer course activities," *Educational Technology & Society*, vol. 19, pp. 351-364, Jul. 2016.

[9] A. Acharya and D. Sinha, "An intelligent web-based system for diagnosing student learning problems using concept maps," *Journal of Educational Computing Research*, vol. 55, pp. 323-345, Jun. 2017.

[10] L. Campbell, "Concept mapping: An 'Instagram' of students' thinking," *Social Studies*, vol. 107, pp. 74-80, Feb. 2016.

[11] P. B. Ferdinand, E. R. Johnston, Jr., P. J. Cornwell and B. Self, *Vector Mechanics for Engineers: Dynamics* (12th edition). New York, NY: McGraw-Hill Education, 2018.

[12] S. F. Barrett, E. W. LeFevre, J. W. Steadman, J. S. Tietjen, K. R. White and D. L. Whitman, *Using the Fundamentals of Engineering (FE) Examination as an Outcomes Assessment Tool*. Seneca, SC: National Council of Examiners for Engineering and Surveying, 2010.

[13] P. J. Cornwell, "Concept maps in the mechanical engineering curriculum," in *Proceedings of the 1996 ASEE Annual Conference & Exposition*, Washington, DC, USA, June 23-26, 1996.

[14] R. C. Hibbeler, *Engineering Mechanics Dynamics* (14th edition). Upper Saddle River, NJ: Pearson Prentice Hall, 2015.