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Using Students-Generated Concept Maps to Assess Students' Conceptual Understanding in a Foundational Engineering Course

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Abstract

This paper reports some results of an ongoing engineering education project funded by the NSF TUES-Type 1 program. Research has shown that conceptual understanding plays a critical role in students' problem-solving performance. Assessing conceptual understanding is important in order to design the most appropriate pedagogy to improve students' problem-solving performance. The conventional way to assess conceptual understanding is to conduct assessment tests (such as the Concept Inventory Test) and/or interviews. In the present study, which involves student learning in a foundational engineering dynamics course, conceptual understanding was assessed through student-generated concept maps. Guided by active learning theory, students developed their own concept maps after they had learned an engineering dynamics theme (i.e., a chapter in a dynamics textbook). Student-generated concept maps were closely examined. This paper presents a representative set of concept maps generated by students who took an engineering dynamics course in a recent semester. The results show that student-generated concept maps provide a significant amount of information on students' understanding and/or misunderstandings of relevant concepts, and can be used as a supplemental tool to assess students' conceptual understanding in this foundational engineering course.

Importance of conceptual understanding in engineering dynamics

Engineering dynamics is a sophomore-level, foundational course that plays a crucial role in many undergraduate engineering programs such as mechanical, aerospace, civil, biological, and biomedical engineering programs. Extended from college physics mechanics courses, the course covers numerous fundamental concepts; for example, displacement, force, velocity, acceleration, mass momentum of inertia, work, energy, impulse, momentum, the Principle of Work and Energy, the Conservation of Energy, the Principle of Impulse and Momentum, and the Conservation of Momentum.[1-3]

Engineering dynamics, however, is also widely regarded as one of the most difficult courses to succeed in. Many students use phrases such as, "much harder than statics," "extremely difficult," "very challenging," and "are afraid of it," to describe their perspectives about this course. It was reported that on the standard Fundamentals of Engineering examination in 2009, the national average score on the dynamics exam was only 53%. [4]

One of the primary reasons that students performed poorly in engineering dynamics is that students lack a solid understanding of fundamental concepts involved in this course.[5, 6] For example, students do not comprehend the difference and relationship between the Principle of Work and Energy and the Conservation of Energy. When given a dynamics problem that involves friction, students mistakenly choose to apply the Conservation of Energy for problem solving. In another example, students do not understand that a rigid body not only has mass but also has a mass moment of inertia. When calculating the kinetic energy for a rigid body

undergoing a general plane motion, students consider only the translational component and miss the rotational component of the kinetic energy.

To improve students' performances in engineering dynamics, it is necessary to first assess their conceptual understanding, and misunderstandings as well, so that appropriate pedagogy can be subsequently designed or chosen to address identified issues. The conventional way to assess students' conceptual understanding is to conduct assessment tests (such as the Concept Inventory test[7]) and/or student interviews. Gray et al.[7] have developed a Dynamics Concept Inventory that consists of a set of multiple-choice questions to assess 11 concepts and misconceptions in engineering dynamics; for example, "different points on a rigid body have different velocities and accelerations, which vary continuously;" "if the net external force on a body is not zero, then the mass center must have an acceleration and it must be in the same direction as the force;" and "angular velocities and angular accelerations are properties of the body as a whole and can vary with time."

Concept mapping

Concept mapping is a graphical tool for knowledge organization, representation, and elicitation. It was first developed at Cornell University in 1972 by Joseph Novak and his colleagues who sought to follow and understand changes in children's knowledge of science.[8] In a concept map, concepts are arranged in a hierarchical or network form, with labeled nodes (in circles or boxes) denoting concepts, and linking words or phrases specifying relationships among concepts. Two or more concepts that are connected by linking words or phrases form a proposition. Figure 1 is a concept map that shows the structure and characteristics of concept maps. [9]

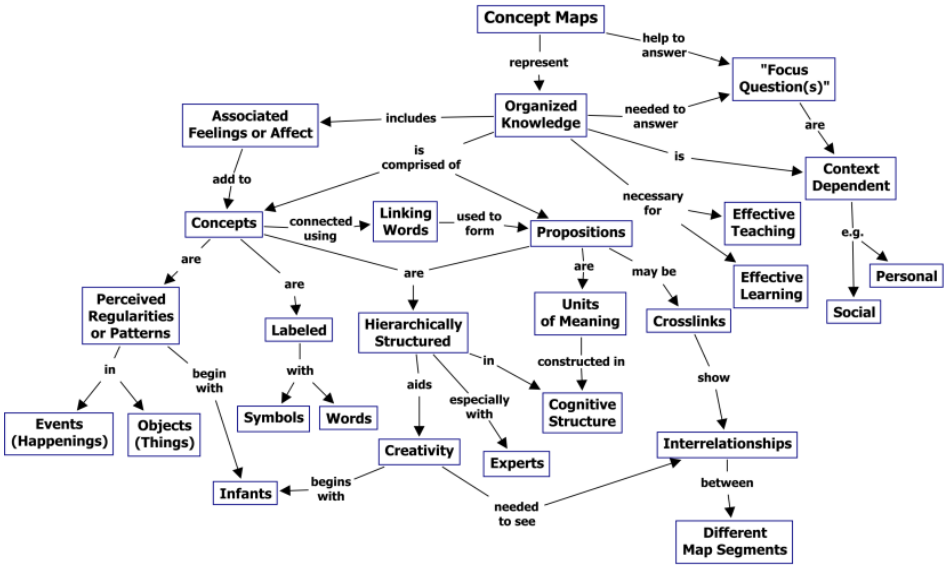

Figure 1. The structure and characteristics of concept maps [9]

Concept mapping has been adopted in teaching and learning in nearly every discipline ranging from STEM (Science, Technology, Engineering, and Mathematics), psychology, and medicine to

business, economics, accounting, and history.[10-13] For example, Egelhoff et al.[14] developed concept maps to teach a mechanics of materials course. Darmofal et al.[15] reported that instructors at MIT have developed a variety of concept maps to teach a wide range of courses including basic thermodynamics, structures, signals and systems, dynamics, controls, advanced aerodynamics, and thermal energy.

The uniqueness and the goal of the present study

Extensive literature review shows that the vast majority of concept maps are developed by instructors. During lectures, instructors show students concept maps, and students learn by watching concept maps and listening to instructors' explanations. For example, Cornwell[6] and Ellis et al.[16] developed concept maps to teach dynamics and continuum mechanics. They put their concept maps in front of classes for students to watch. Learning by "watching and listening" is in fact the approach to passive learning.

The present study, which is currently funded by the NSF TUES-Type 1 program, takes the approach of active learning. Students, rather than instructors, develop concept maps. Students need to create their own concept maps, and figure out how different concepts are connected and what the relationships between different concepts are. In other words, students take the ownership of their concept maps, and hence are actively engaged in the learning process.

The goal of the present study is to investigate whether student-generated concept maps can be employed as a supplemental tool to assess students' conceptual understanding in engineering dynamics. In the remaining sections of this paper, the research method and data collection are described first. Then, a representative set of concept maps generated by students is presented. These students took an engineering dynamics course taught by the author of this paper in a recent semester. Research findings are reported. Next, the limitations of the present study are discussed. Conclusions are made in the end of the paper.

Research method

The present study was conducted at a public research university in the Western United States. Student participants were from three engineering departments, including Mechanical and Aerospace Engineering, Civil and Environmental Engineering, and Biological Engineering. They took an engineering dynamics course in a recent semester. At the beginning of the semester, students were taught how to use IHMC Cmap Tools, a free online software that can be downloaded at http://cmap.ihmc.us, to construct a concept map. This user-friendly software allows students to construct and edit concept maps on their personal computers. Example concept maps were also presented to students for them to understand the general structure of a concept map and how to build concept maps step by step. These steps are described in the following paragraph.

First, students needed to write down as many of the concepts they have learned as possible. Then, students needed to figure out logical connections and relationships between these concepts, and accordingly place these concepts in their reasonable positions on a concept map. With IHMC Cmap Tools, students can easily move a concept from one place to another and edit the

entire concept map. Finally, students submitted their concept maps to the instructor. The instructor then assessed students' conceptual understanding and/or misunderstanding based on student-generated concept maps.

It must be pointed out that engineering covers many learning themes (i.e., different chapters of a dynamics textbook[1]), and each theme includes many concepts. Students were required to develop a concept map for each learning theme, i.e., each chapter of a dynamics textbook,[1] so students would not feel overwhelmed by the complexity of a concept map. The more complex a concept map is, the heavier the cognitive load associated with it is.

Student-generated concept maps and research findings

A representative set of concept maps generated by students are presented in the following paragraphs. These concept maps were selected from the first learning theme – kinematics of a particle – which is the 12th chapter of Hebbeler's dynamics textbook.[1] This chapter includes the following ten sections:

Section 1: Introduction
Section 2: Rectilinear Kinematics: Continuous Motion
Section 3: Rectilinear Kinematics: Erratic Motion
Section 4: General Curvilinear Motion
Section 5: Curvilinear Motion: Rectangular Components
Section 6: Motion of a Projectile
Section 7: Curvilinear Motion: Normal and Tangential Components
Section 8: Curvilinear Motion: Cylindrical Components
Section 9: Absolute Dependent Motion Analysis of Two Particles
Section 10: Relative-Motion of Two Particles Using Translating Axes

Each section covers a variety of fundamental concepts. Figures 2-4 show three representative concept maps generated by three different students after they completed the learning of the above sections. Note that the number of concepts included in each figure are different, which reflects the different amount of time that the students spent in creating their concept maps. Also note that the ways in which concepts are organized on their maps are different among all three students.

In Fig. 1, the student arranged all concepts around the center of the map: "Chapter 12: Kinematics of a particle." A close examination of the map shows that the map consists of three portions: the upper portion (starting from the concept of "rectilinear kinematics"), the right portion (starting from the concept of "motion between two particles"), and a combined left-and-bottom portion (starting from the concept of "curvilinear motion"). The student demonstrated a solid understanding of all concepts learned in this chapter.

On the topic of "rectilinear kinematics," the student clearly shows the relationships and differences between "position" and "change in position;" "displacement" and "change in displacement;" and "velocity" and "change in velocity." Equations are also included on the map to show how relevant concepts are defined.

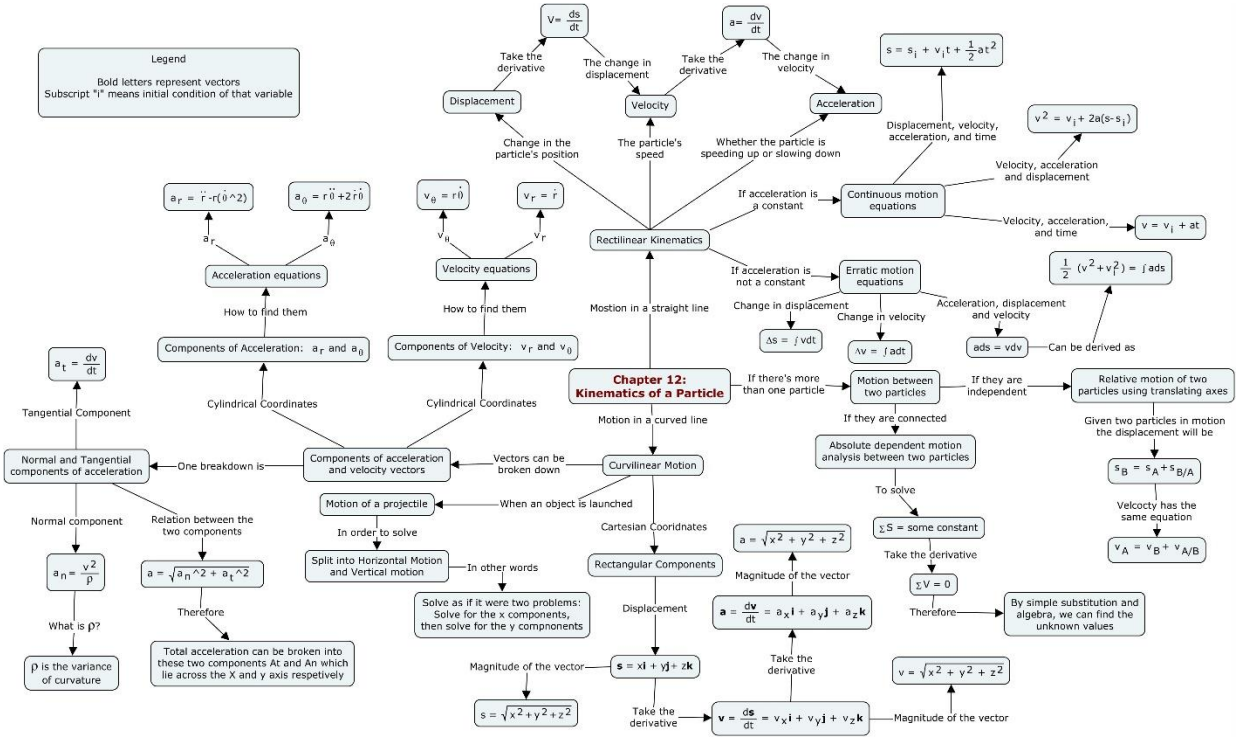

Figure 2: A concept map generated by a student: Example 1

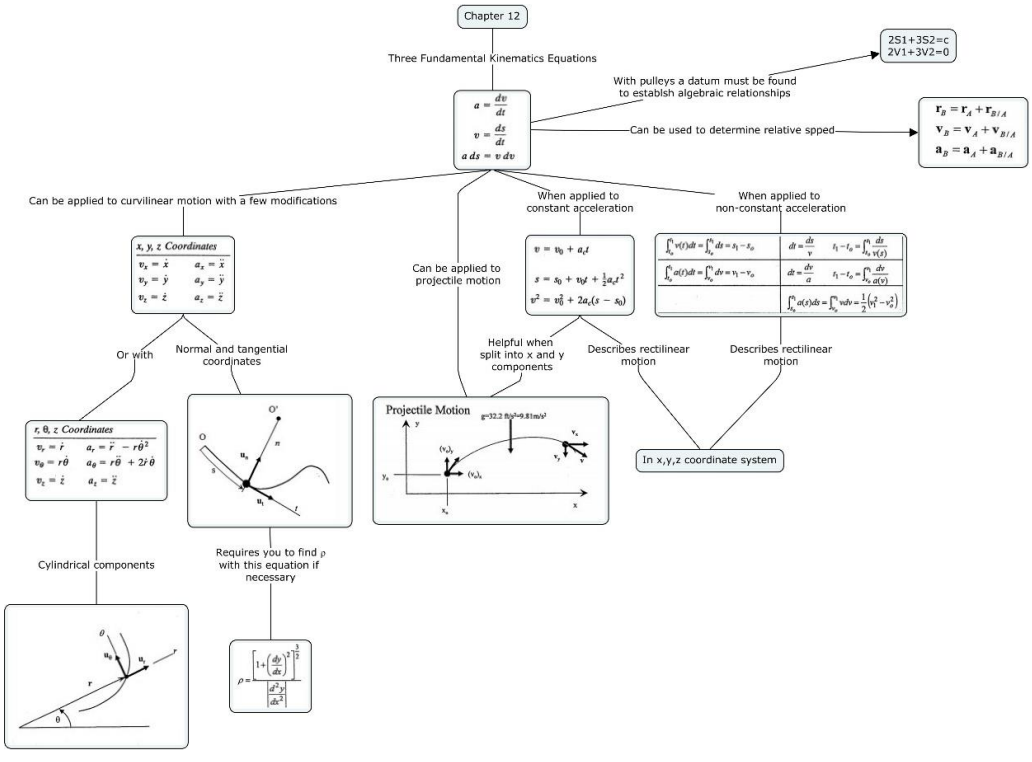

Figure 3: A concept map generated by a student: Example 2

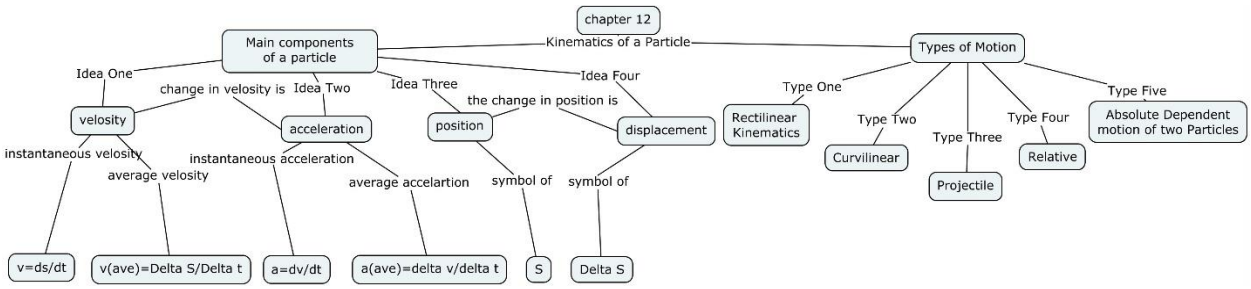

Figure 4: A concept map generated by a student: Example 3

On the topic of "motion between two particles," the student clearly shows the different conditions under which one should make an analysis for "absolute dependent motion" and for "relative motion." The problem-solving strategies dealing with these two different types of motions are also included on the map.

On the topic of "curvilinear motion," the student clearly demonstrated his understanding of velocity and acceleration components using three different coordinate systems: Cartesian coordinates, normal and tangential coordinates, and cylindrical coordinates.

In Fig. 3, the student took a top-down approach to arranging concepts. However, many important concepts are missing from the map. The map is full of equations and figures. Figure 4 contains minimal concepts and also shows that the student had a conceptual misunderstanding about motion. On the map of Fig. 4, motion is divided into five types: rectilinear, curvilinear, projectile, relative, and absolute dependent. In fact, a motion is either rectilinear or curvilinear. Projectile motion is a special case of curvilinear motion. When involving more than one particle, relative motion or absolute dependent motion analyses is needed.

Limitations of the present study

The present study has two primary limitations. First, all concept maps were collected from one institution only. As students at different institutions have different backgrounds and experience, their concept maps might vary significantly from institution to institution. Second, all concept maps collected in the present study were generated by students who were taught by the same instructor. As teaching makes a difference in student learning, students taught by different instructors might generate significantly different concept maps. In the future study, these two limitations will be addressed by involving instructors and students at other institutions across the nation.

Conclusions

Concept mapping is a powerful graphical tool for knowledge organization, representation, and elicitation. The conventional way is for instructors to develop concept maps for students, and students to learn by passive watching and listening. The present study takes the active learning

approach by asking students to develop their own concept maps. Therefore, students take ownership of their concept maps and are actively engaged in the learning process.
This paper has described how this active learning approach was implemented in engineering dynamics, a foundational yet difficult undergraduate engineering course. The results show that student-generated concept maps provide a significant amount of information on students' understanding and/or misunderstandings of relevant concepts and can be used as a supplemental tool to assess students' conceptual understanding in this foundational engineering course.

Acknowledgements

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Bibliography

[1] Hibbeler, R. C., 2012, Engineering Mechanics Dynamics (13th edition), Pearson Prentice Hall, Upper Saddle River, NJ.
[2] Beer, F. P., Jr., Johnston, E. R., Clausen, W., Eisenberg, E., and Cornwell, P., 2009, Vector Mechanics for Engineers: Dynamics, McGraw-Hill, Columbus, OH.
[3] Bedford, A. and Fowler, W., 2009, Engineering Mechanics Dynamics (5th edition), Prentice Hall, Upper Saddle River, NJ.
[4] Barrett, S. F., LeFevre, E. W., Steadman, J. W., Tietjen, J. S., White,K. R., and Whitman, D. L., 2010, Using the Fundamentals of Engineering (FE) Examination as an Outcomes Assessment Tool, National Council of Examiners for Engineering and Surveying, Seneca, SC.
[5] Streveler, R. A., Geist, M. R., Ammerman, R. F., Sulzbach, C. S., Miller, R. L., Olds, B. M., and Nelson, M. A., 2006, "Identifying and Investigating Difficult Concepts in Engineering Mechanics and Electrical Circuits," *Proceedings of the 2006 ASEE Annual Conference & Exposition*, Chicago, IL.
[6] Cornwell, P. J., 2000, "Dynamics Evolution – Change or Design," *Proceedings of the 2000 ASEE Annual Conference & Exposition*, St. Louis, MO.
[7] Gray, L. G., Costanzo, F., Evans, D., Cornwell, P., Self, B., and Lane, J. L., 2005, "The Dynamics Concept Inventory Assessment Test: A Progress Report and Some Results," *Proceedings of the 2005 ASEE Annual Conference & Exposition*, Portland, OR.
[8] Novak, J. D., and Gowin, D. B., 1984, Learning How to Learn, Cambridge University Press, New York, NY.
[9] Novak, J. D., and Cañas, A. J., 2008, The Theory Underlying Concept Maps and How to Construct and Use Them, Florida Institute for Human and Machine Cognition Technical Report, IHMC CmapTools 2006-01 Rev 2008-01.
[10] Sedig, K., Rowhani, S. and Liang, H. N., 2005, "Designing Interfaces That Support Formation of Cognitive Maps of Transitional Processes: An Empirical Study," *Interacting with Computers*, 17(4), pp. 419-452.
[11] Gros, B., 2002, "Knowledge Construction and Technology," *Journal of Educational Multimedia and Hypermedia*, 11(4), pp. 323-343.
[12] Horton, P. B., McConney, A. A., Gallo, M., Woods, A. L., Senn, G. L., and Hamelin, D., 1993, "An Investigation of the Effectiveness of Concept Mapping as an Instructional Tool," *Science Education*, 77 (1), pp. 95-111.
[13] Nesbit, J. C., and Adesope, O. O., 2006, "Learning with Concept and Knowledge Maps: A Meta-Analysis," *Review of Educational Research*, 76(3), pp. 413-448.
[14] Egelhoff, C. J., Podoll, N., and Tarhini, K., 2010, "Work in Progress - A Concept Map for Mechanics of Materials," *Proceedings of the 40th ASEE/IEEE Frontiers in Education Conference*, Washington, DC, October 27-30, 2010.

[15] Darmofal, D. L., Soderhoml, D. H., and Brodeur, D. R., 2002, "Enhancing Conceptual Understanding with Concept Maps and Concept Questions," *Proceedings of the 2002 ASEE Annual Conference & Exposition*, Montreal, Quebec, Canada, June 16-19, 2002.
[16] Ellis, G. W., Rudnitsky, A. and Silverstein, B., 2004, "Using Concept Maps to Enhance Understanding in Engineering Education," *International Journal of Engineering Education*, 20(6), pp. 1012-1021.