A Qualitative Analysis of Student-constructed Concept Maps in a Foundational Undergraduate Engineering Course

Ning Fang
Department of Engineering Education, Utah State University, Logan, UT, U.S.A.

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Abstract: This work-in-progress report (Position Paper) presents a qualitative analysis of student-constructed concept maps in engineering dynamics – a high-enrollment, high-impact, foundational undergraduate engineering course. Using a computer software program called IHMC Cmap Tools, the students who participated in the present study constructed their own concept maps to demonstrate their understanding of a variety of concepts they had learned. The present study investigates students' purposes when they construct their own concept maps to learn. The results show that students construct their concept maps for five primary purposes: to describe the relationships among relevant concepts, to connect important equations, to illustrate the evolution of concepts, to incorporate figures into concept maps, and to integrate problem-solving procedures into concepts. These research findings help develop a better understanding of how students learn, and therefore may help instructors develop or adopt the most appropriate instructional strategies to improve student learning outcomes.

1 INTRODUCTION

The U.S. National Research Council report "How People Learn" (Bransford, Brown, and Cocking, 2000) emphasizes that "to develop competence in an area of inquiry, students must: (a) have a deep foundation of factual knowledge, (b) understand facts and ideas in the context of a conceptual framework, and (c) organize knowledge in ways that facilitate retrieval and application." To meet these requirements, a variety of innovative and active teaching and learning strategies, such as problem-based learning, project-based learning, collaborative learning, and cooperative learning have been developed and implemented in various educational settings.

Concept mapping is a graphical tool for knowledge organization, representation, and elicitation (Atapattu, Falkner, and Falkner, 2014; Castles and Lohani, 2010; Novak, 1984). It has been proven effective in helping students develop a better understanding of various concepts (Darmofal, Soderhoml, and Brodeur, 2002; Ellis, Rudnitsky, and Silverstein, 2004; Horton, McConney, Gallo, Woods, Senn, and Hamelin, 1993; Moore, Pierce, and Williams, 2012; Nesbit and Adesope, 2006; Sedig, Rowhani, and Liang, 2005).

For example, Nesbit and Adesope (2006) conducted a meta-analysis of 55 experimental and quasi-experimental studies on concept mapping, involving 5,818 students from Grade 4 to postsecondary in science, psychology, statistics, and nursing. They found that in comparison with traditional learning activities (e.g. reading text documents and participating in class discussions), concept mapping engaged students more in the learning process, and was more effective in achieving knowledge retention and transfer.

Engineering dynamics is a high-enrollment, high-impact, foundational undergraduate engineering course that nearly all students in mechanical, aerospace, civil, environmental, biological, and biomedical engineering programs are required to take. This sophomore-level foundational course covers a broad spectrum of foundational concepts, such as force, velocity, acceleration, work, energy, impulse, momentum, and vibration (Bedford and Fowler, 2009; Beer, Johnston, Clausen, Eisenberg, and Cornwell, 2009; Hibbeler, 2012). Many dynamics principles and laws (also called concepts), such as the Principle of Work and Energy and the Principle of Linear Impulse and Momentum, are built upon these foundational concepts.

However, dynamics is widely regarded as one of the most difficult courses to succeed in. Many

Fang N..
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students lack a solid understanding of dynamics concepts; thus they perform poorly in this course (Gray, Costanzo, Evans, Cornwell, Self, and Lane, 2005). It is reported that on the standard Fundamentals of Engineering examination in the U.S. in 2009, the national average score on the dynamics portion was only 53% (Barrett, LeFevre, Steadman, Tietjen, White, and Whitman, 2010).

In this study, concept mapping was employed to help students develop a better understanding of foundational concepts in engineering dynamics. To promote active learning, students (rather than the instructor) constructed their own concept maps after they had learned relevant concepts.

Prior to this study, extensive literature review was performed using a variety of popular databases such as the Education Resources Information Center, Science Citation Index, Social Science Citation Index, Engineering Citation Index, Academic Search Premier, and the American Society of Engineering Education (ASEE) annual conference proceedings (1995-2014). The Proceedings of the International Conference on Computer Supported Education were also examined. The results show that the vast majority of relevant literature focuses on the importance and effectiveness of concept maps (e.g., Ellis et al., 2004; Nesbit and Adesope, 2006), instructor- or expert-developed concept maps (e.g., Darmofal et al., 2012; Moore et al., 2012), and the scoring and evaluation of concept maps (e.g., Besterfield-Sacre, Gerchak, Lyons, Shuman, and Wolfe, 2004; Richard, Defranco, and Jablokow, 2014; Stoddart, Abrams, Gasper, and Canaday, 2000; Walker and King, 2003).

The present study investigates students' purposes when they construct their own concept maps to learn. The research findings from the present study help develop a better understanding of how students learn, and therefore help instructors develop or adopt the most appropriate instructional strategies to improve student learning outcomes.

In the remaining sections of the paper, a computer software program that students employed to construct their own concept maps is briefly introduced. Then, the research question and the data collection method are described, followed by the description of representative results as well as discussions. Next, a limitation of the present study is presented. Finally, conclusions are made at the end of this paper.

2 COMPUTER SOFTWARE PROGRAM THAT STUDENTS EMPLOYED TO CONSTRUCT THEIR CONCEPT MAPS

The students who participated in the present study employed a free computer software program called IHMC Cmap Tools (downloaded at http://cmap.ihmc.us). With a user-friendly interface, this computer software program is specially developed for constructing concept maps (Novak and Cañas, 2008). In general, students can self-teach themselves how to use this computer software program within 10-30 minutes. Figure 1 shows the user interface of this computer software program. Students can edit and modify their concept maps very easily.

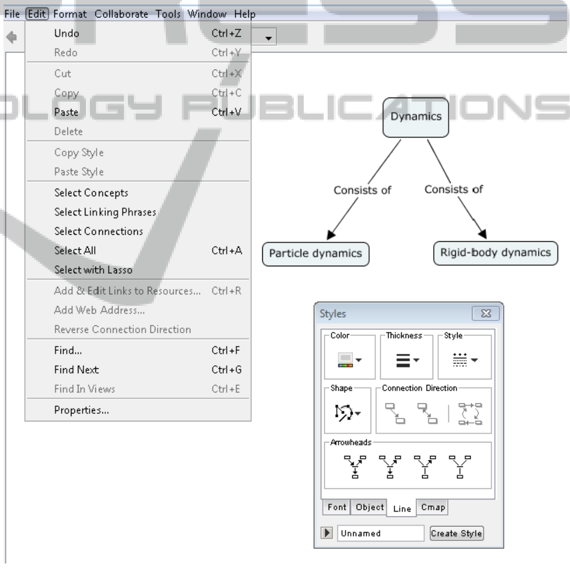

Figure 1: The user interface of IHMC Cmap Tools.

3 RESARCH QUESTION AND DATA COLLECTION

The research question of the present study is: For what purposes did students construct their own concept maps to learn?

A total of 71 undergraduate students who recently took an engineering dynamics course from the author of this paper participated in the present study. The 71 students, including 64 males and 7 females, were primarily from three departments: mechanical and aerospace engineering, civil and environmental engineering, and biological engineering. Table 1 shows student demographics. As seen from Table 1, the majority of students were from either the mechanical and aerospace department (47.9%) or the civil and environmental engineering department (29.6%).

Table 1: Student demographics.

Total	Mech. Aerospa. Engng.	Civil Environme. Engng.	Bio. Engng.	Other
71	34	21	11	5

Prior to the present study, all student participants signed a Letter of Informed Consent approved by an Institutional Review Board. As many students did not have previous experience in constructing a concept map, the following instruction was provided to them on how to construct a concept map.

First, students needed to write down as many of the concepts they had learned as possible. Then, students needed to figure out logical connections and relationships between those concepts, and accordingly place the concepts in their reasonable positions on a concept map. Students were asked to use the free IHMC Cmap Tools to generate a concept map after they had learned each learning topic, i.e., each chapter of a dynamics textbook (Hibbeler, 2012). With IHMC Cmap Tools, students could easily move a concept from one place to another and edit the entire concept map. Finally, students submitted their concept maps to the instructor to conduct a qualitative analysis.

4 RESULTS AND DISCUSSIONS

Figures 2-11 show 10 representative concept maps generated by 10 different students. The results show that students constructed their concept maps for five learning purposes. In the following paragraphs, each purpose is described using two examples.

Purpose 1: Describe the relationships among relevant concepts (Figures 2 and 3). Figure 2 describes the relationship between work and energy and how the two concepts combine to form a new concept: the Principle of Work and Energy. Figure 3 describes the parallel relationships among three coordinate systems: cylindrical, normal and tangential, and rectangular coordinates.

Purpose 2: Connect important equations (Figures 4 and 5). Figure 4 shows how equations for calculating the work done by a constant force and by a variable force are connected. Figure 5 shows how equations for determining displacement, velocity, and acceleration are connected.

Purpose 3: Illustrate the evolution of concepts (Figures 6 and 7). Figure 6 shows how displacement, velocity, and acceleration are evolved. Figure 7 shows Newton's Second Law is evolved to form the Principle of Linear Impulse and Momentum as well as the Conservation of Linear Momentum.

Purpose 4: Incorporate figures into concept maps (Figures 8 and 9). Figure 8 incorporates into the map two figures, one for normal and tangential coordinates and the other for cylindrical coordinates. Figure 9 integrates into the map a figure showing oblique impact.

Purpose 5: Integrate problem-solving procedures into concept maps (Figures 10 and 11). Figure 10 shows that a free-body diagram and a kinetic diagram must be drawn before applying Newton's Second Law. Figure 11 shows a procedure to apply the Principle of Angular Impulse and Momentum.

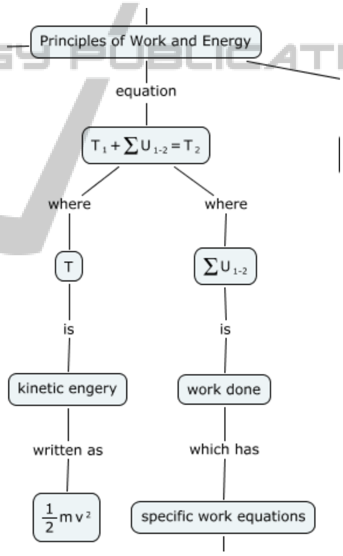

Figure 2: Describe the relationships among relevant concepts: Example 1.

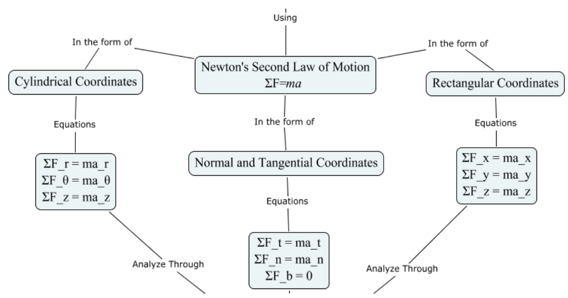

Figure 3: Describe the relationships among relevant concepts: Example 2.

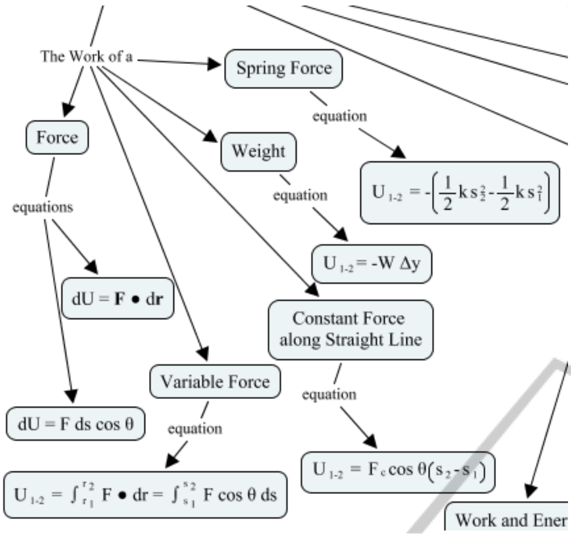

Figure 4: Connect important equations: Example 1.

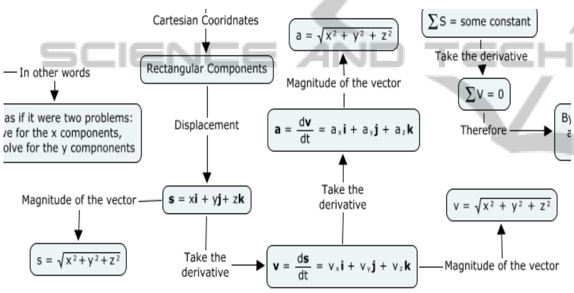

Figure 5: Connect important equations: Example 2.

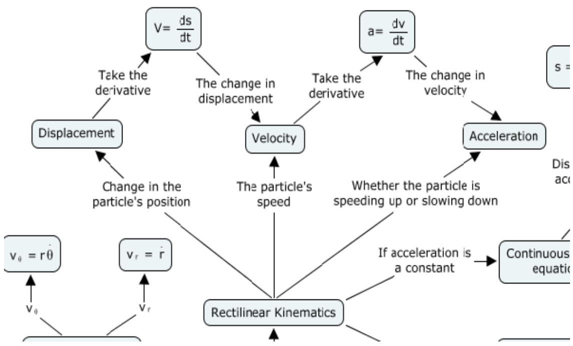

Figure 6: Illustrate the evolution of concepts: Example 1.

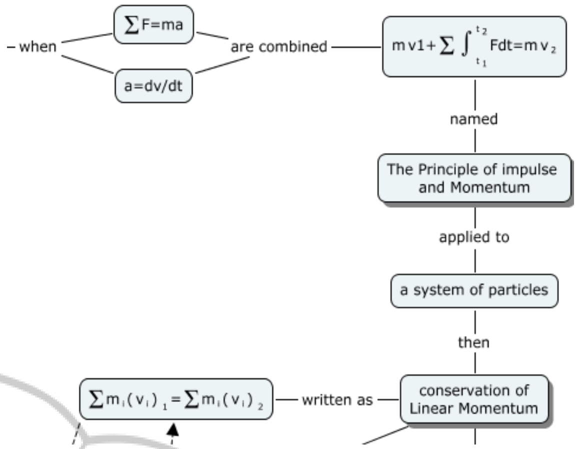

Figure 7: Illustrate the evolution of concepts: Example 2.

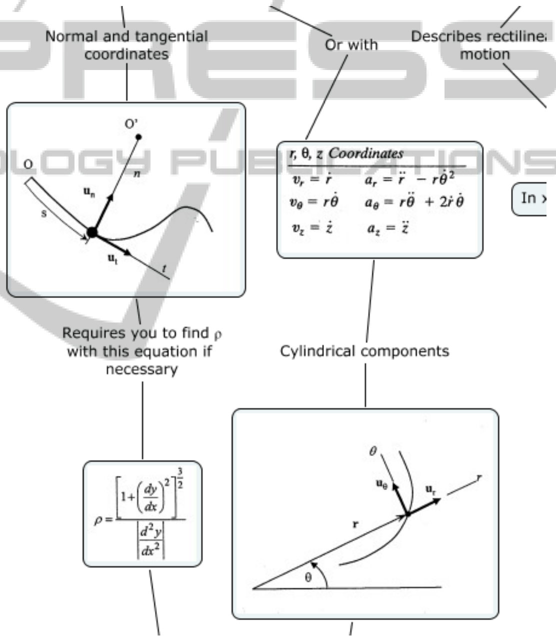

Figure 8: Incorporate figures into concept maps: Example 1.

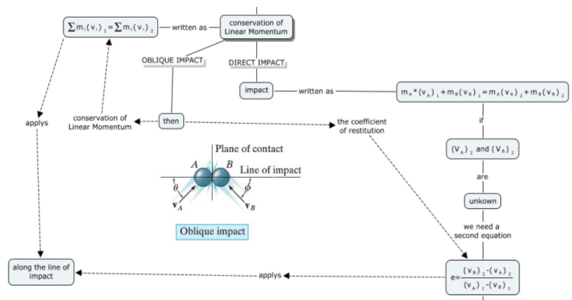

Figure 9: Incorporate figures into concept maps: Example 2.

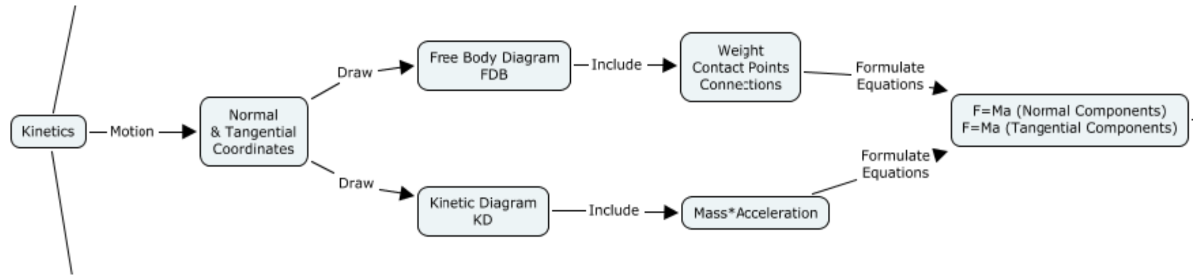

Figure 10: Integrate problem-solving procedures into concept maps: Example 1.

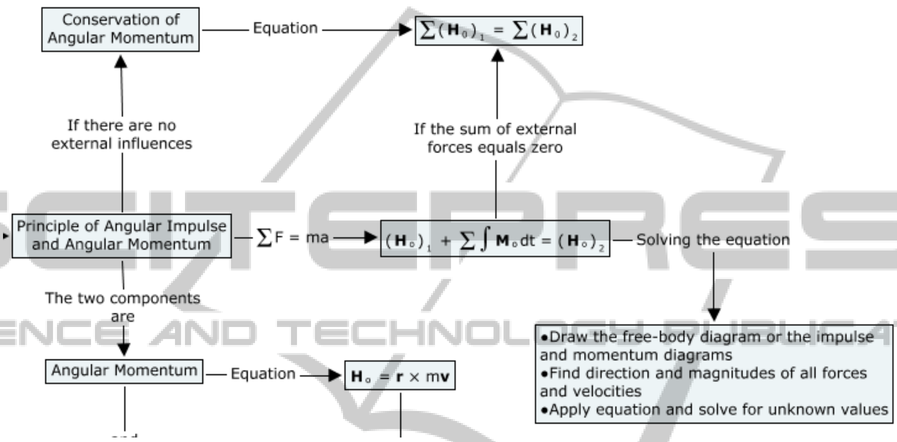

Figure 11: Integrate problem-solving procedures into concept maps: Example 2.

A traditional concept map does not include mathematical equations, figures, or problem-solving procedures because these are not typically regarded as concepts (Novak and Gowin, 1984). However, the present study shows that students were creative when they constructed their own concept maps. Nearly all of the concept maps that students constructed in the present study included mathematical equations. Some concept maps were full of mathematical equations. This phenomenon confirms the statement by Cornwell (2000) that "in many students' minds, the [dynamics] course seemed to be a collection of mathematical manipulations or 'finding the right equation'".

5 LIMITATION OF THE PRESENT STUDY

The primary limitation of the present work-in-progress study is that all student participants were from one public research institution only. Because students at different institutions may have different backgrounds and experience, the concept maps may vary from institution to institution. Therefore, there might be other learning purposes for which students construct their concept maps. Students at other institutions would be included in the future study.

6 CONCLUSIONS

Concept mapping is a powerful graphical tool for knowledge organization, representation, and elicitation. The results of an extensive literature review using a variety of popular databases reveals that the present work-in-progress study is the first one that investigates the learning purposes for which students construct their own concept maps.

The present study has involved 71 engineering students. A qualitative analysis shows that students constructed their own concept maps for five learning purposes: 1) to describe the relationships among relevant concepts, 2) to connect important equations, 3) to illustrate the evolution of concepts, 4) to incorporate figures into concept maps, and 5) to inte grate problem-solving procedures into concept maps. These research findings help develop a better understanding of how students learn, and therefore help instructors develop or adopt the most appropriate instructional strategies to improve student learning outcomes.

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REFERENCES

Atapattu, T., Falkner, K., and Falkner, N., 2014. Evaluation of concept importance in concept maps mined from lecture notes. In *Proceedings of the 6th International Conference on Computer Supported Education*, Barcelona, Spain.

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.

Bedford, A., Fowler, W., 2009. *Engineering mechanics dynamics*, Prentice Hall. Upper Saddle River, NJ, 5th edition.

Beer, F. P. Jr., Johnston, E. R., Clausen, W., Eisenberg, E., and Cornwell, P., 2009. *Vector mechanics for engineers: dynamics*, McGraw-Hill. Columbus, OH.

Besterfield-Sacre, M., Gerchak, J., Lyons, M. R., Shuman, L. J., and Wolfe, H., 2004. Scoring concept maps: an integrated rubric for assessing engineering education. *Journal of Engineering Education*, 93, 105-115.

Bransford, J. D., Brown, A. L., and Cocking, R. R., (editors), 2000. *How people learn, brain, mind, experience, and school*, National Research Council, National Academy Press. Washington, DC.

Castles, R., Lohani, V., 2010. Utilizing software-generated concept maps based on customized concept inventories to illustrate student learning and knowledge gaps. In *Proceedings of the 2010 ASEE Annual Conference & Exposition*, Louisville, KY.

Cornwell, P. J., 2000. Dynamics evolution – change or design. In *Proceedings of the 2000 ASEE Annual Conference & Exposition*, St. Louis, MO.

Darmofal, D. L., Soderhoml, D. H., and Brodeur, D. R., 2002. Enhancing conceptual understanding with concept maps and concept questions. In *Proceedings of the 2002 ASEE Annual Conference & Exposition*, Montreal, Quebec, Canada.

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), 1012-1021.

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. In *Proceedings of the 2005 ASEE Annual Conference & Exposition*, Portland, OR.

Hibbeler, R. C., 2012. *Engineering mechanics dynamics*, Pearson Prentice Hall. Upper Saddle River, NJ, 13th edition.

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), 95-111.

Moore, J. P., Pierce, R. S., and Williams, C. B., 2012. Towards an “adaptive concept map”: creating an expert-generated concept map of an engineering statics curriculum. In *Proceedings of the 2012 ASEE Annual Conference & Exposition*, San Antonio, TX.

Nesbit, J. C., Adesope, O. O., 2006. Learning with concept and knowledge maps: a meta-analysis. *Review of Educational Research*, 76, 413-448.

Novak, J. D., Gowin, D. B., 1984. *Learning how to learn*, Cambridge University Press. New York, NY.

Novak, J. D., 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.

Richard, S. S., Defranco, J. F., and Jablokow, K., 2014. A set of guidelines for the consistent assessment of concept maps. *International Journal of Engineering Education*, 30, 1072-1082.

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), 419-452.

Stoddart, T., Abrams, R., Gasper, E., and Canaday, D., 2000. Concept maps as assessment in science inquiry learning – a report of methodology. *International Journal of Science Education*, 22 (12), 1221-1246.

Walker, J. M., King, P. H., 2003. Concept mapping as a form of student assessment and instruction in the domain of bioengineering. *Journal of Engineering Education*, 92, 167-178.