

# An Analysis of Student Experiences with Concept Mapping in a Foundational Undergraduate Engineering Course\*

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Concept mapping is a powerful graphical technique for helping learners organize knowledge and visualize connections and relationships between relevant concepts. The present study is an investigation of student experiences with concept mapping in a foundational undergraduate engineering course titled Engineering Dynamics. A total of 165 undergraduate engineering students from two recent semesters participated in the present study. This paper provides representative examples of student-generated concept maps. Student comments collected at the end of each semester were analyzed using content analysis. Students provided positive feedback, for example, concept mapping helped students make connections between concepts; reviewed what students had learned; visualized, understood and organized concepts; saw the bigger picture of dynamics; and thought more clearly about concepts. Students also provided negative feedback, for example, concept mapping was busy work, did not help in understanding concepts, was a small percentage of credit of the final course grade, and students had other ways to learn concepts. The results reported in this paper are useful for engineering educators and researchers to develop a better understanding of the strengths and limitations of concept mapping in teaching and learning engineering courses.

**Keywords:** concept mapping; student experiences; engineering dynamics

## 1. Introduction

Undergraduate students in many engineering majors, such as mechanical, aerospace, civil, and environmental engineering, are typically required to take a series of foundational engineering mechanics courses, for example, statics, dynamics, and strength of materials [1]. These mechanics courses serve as an essential basis for students to learn subsequent, more advanced courses, such as machine design, structural design, and advanced dynamics and vibration [2, 3].

Out of these courses, dynamics is the most challenging course for many students because it covers numerous fundamental concepts: types of motion, acceleration and its components in various coordinate systems, force, power, work, energy, impulse, and momentum, to name a few. A solid understanding of these fundamental concepts is essential for successful problem solving in engineering dynamics [4–6].

Consequently, student understanding in dynamics is often a significant concern. Many students do not have a solid conceptual understanding, fail to see the connections and relationships between relevant concepts, and often apply wrong concepts in problem solving [7, 8]. In the recent standard Fundamentals of Engineering examination in the U.S., the national average score on the Dynamics exam was only 53% [9].

A variety of educational techniques, such as computer simulation and animation, multimedia,

demonstrations and experimentations, and concept mapping, have been developed to help students understand important concepts and improve their problem-solving skills in engineering mechanics, including dynamics [5–7, 10, 11]. Among these educational techniques, concept mapping is particularly helpful for students to organize knowledge and visualize connections and relationships between relevant concepts [12, 13]. In a concept map, concepts are arranged in a hierarchical or network form, with labelled nodes (in circles or boxes) denoting concepts, and linking words or phrases specifying relationships between concepts. Two or more concepts that are connected by linking words or phrases form a proposition [14].

Extensive research has shown that concept mapping improves student conceptual understanding and motivation for learning in a variety of disciplines in science [15–19] and engineering [20–22]. For example, Horton et al. [18] conducted a comprehensive literature review involving three computerized databases: the Educational Resources Information Center (ERIC), Dissertation Abstracts International, and Psychological Abstracts. Based on a meta-analysis of 19 relevant studies, they found that “concept mapping raised individual student achievement in the average study by 0.46 standard deviations, or from the 50th to the 68th percentile” [18]. They concluded that concept mapping has, in general, medium positive effects on student achievement, and large positive effects on student attitudes toward science.

In another example, Elorriaga et al. [20] conducted an experimental study on the use of concept mapping in promoting meaningful learning in a second-year computer engineering course. Their study involved two groups of student participants: a control group who learned without concept mapping, and an experimental group who learned with concept mapping. They reported final exam marks on a scale of zero to six; the mean mark for the experimental group was 5.0, whereas for the control group it was 2.7. The difference in the final exam marks between the experimental and control groups was statistically significant ( $p < 0.01$ ) [20].

The present study focuses on the implementation of concept mapping in a foundational undergraduate engineering dynamics course offered in the College of Engineering at a public research institution in the U.S. A total of 165 student participants who took the course in recent two semesters were involved in the study. This paper describes how concept mapping was implemented during each semester and provides representative examples of student-generated concept maps. Students' written comments about their concept mapping experiences were collected at the end of each semester. Content analysis of student comments was performed to answer the following research question: What were student experiences, both positive and negative, in generating concept maps in engineering dynamics?

The present study investigates both positive and negative experiences of students, which helps the engineering education community develop a better understanding of both the strengths and limitations of concept mapping in teaching and learning engineering courses. The vast majority of existing literature reports positive student experiences only [20, 21, 23, 24]. For example, it is reported that "[A concept map] helps show how all those formulas and concepts are related, which helps me to understand new ones based on old ones I'm already comfortable with" [24]. Negative student comments about concept mapping are rarely reported in existing literature. However, it is also important to understand why some students do not like concept mapping in order to adjust our educational practices to better meet the needs of these students.

It should be noted that the scope of the study is limited to analyzing student experiences with concept mapping based on student comments only. Student comments are self-reported and subjective. An experimental study that involves the comparison between an experimental and a control group to determine how concept mapping affects student learning is beyond the scope of the study and will be conducted in future work.

## 2. Concept mapping in engineering dynamics

### 2.1 Generation of concept maps by students

In the traditional approach to concept mapping in engineering dynamics courses, the instructor develops concept maps for students, and then shows them in lectures [23, 24]. For example, an instructor would construct a concept map prior to the teaching of an engineering dynamics course [23]. The map would be hung on the wall in the corner of the classroom. During lectures, the instructor would point to the map when relevant concepts were introduced. Students would watch the map and listen to the instructor's explanations. This traditional approach to learning is called "watching and listening," an example of passive learning rather than active, as students are not fully and actively engaged in the learning process.

In the present study, students, rather than the instructor, generate the concept maps used in an engineering dynamics course, and figure out themselves how different concepts are connected and related. Students take ownership of their concept maps, and hence are more actively engaged in the process of learning. It should be pointed out that it has been a well-established practice for students to generate their own concept maps in learning many subject matters [12, 14]. However, the results of the literature review show that except the author's own work, little literature has reported that students generated many concept maps of their own in learning the subject of *engineering dynamics*.

At the beginning of the semester, students are introduced the function of concept maps and are also provided a set of example concept maps, so students understand what concept maps look like. In addition, students learn how to draw a concept map by using the free software program IHMC Cmap Tools [25]. This software is specially developed for concept mapping and can be downloaded at <http://cmap.ihmc.us>. Figure 1 shows its graphical user interface. Students can easily move a concept from one place to another and edit an entire concept map.

The IHMC Cmap software tool [25] is only the medium used to display students' concept maps. When generating their own maps, students need to write down as many concepts they have learned as possible, and then figure out logical connections and relationships between those concepts. Finally, they can place the concepts at reasonable positions on the concept map using the IHMC Cmap software. Cmap functions like a word-processing software in the sense that it enables students to write, but does not write for them, an essay. In other words, the

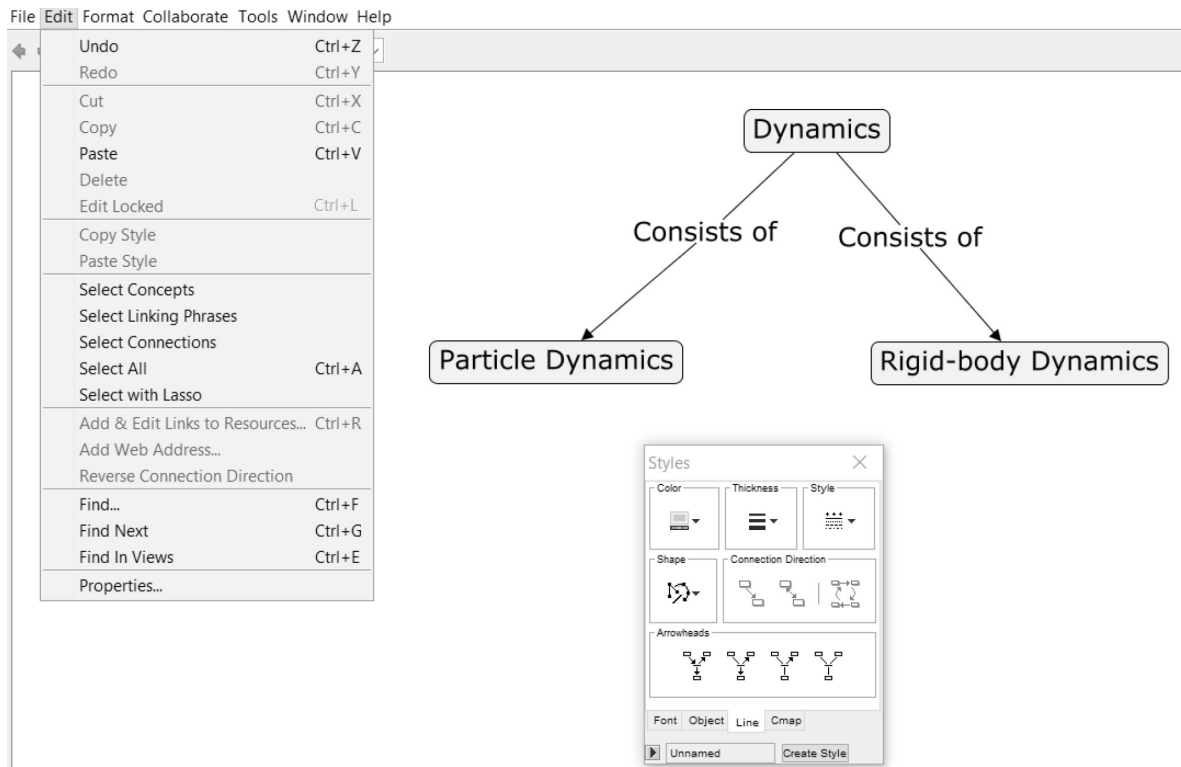


Fig. 1. The computer graphical user interface of IHMC Cmap tool.

IHMC Cmap is only a tool to display, edit, and modify students' maps.

## 2.2 Concepts involved in engineering dynamics

Throughout the semester, students learn the following eight topics in the form of eight textbook chapters [3]:

1. Kinematics of a particle.
2. Kinetics of a particle: force and acceleration.
3. Kinetics of a particle: work and energy.
4. Kinetics of a particle: impulse and momentum.
5. Planar kinematics of a rigid body.
6. Kinetics of a rigid body: force and Acceleration.
7. Kinetics of a rigid body: work and energy.
8. Kinetics of a rigid body: impulse and momentum.

Each topic includes a set of concepts. For example, Topic 1 includes the concepts of displacement, velocity, acceleration, rectilinear motion, curvilinear motion, projectile motion, absolute dependent motion, relative motion, and so on. Topic 5

includes the concepts of translation, rotation about a fixed axis, general plane motion, instantaneous center of zero velocity, relative motion for two rigid bodies, and etc. At the end of the semester, each student generates independently eight concept maps, with each map corresponding to a chapter in the textbook.

## 3. Research method and data collection

### 3.1 Student participants

A total of 165 undergraduates who took engineering dynamics in one of two recent semesters participated in this study. The course was taught by the same instructor (i.e., the author of this paper) using the same textbook [3] and the same syllabus. The 165 student participants included 94 students in Semester A and 71 students in Semester B. Prior to the present study, all students signed a Letter of Informed Consent approved by an Institutional Review Board.

Table 1 shows student demographics in terms of

Table 1. Student demographics

Semester	Mechanical and Aerospace Engineering	Civil and Environmental Engineering	Biological Engineering	Other
Semester A (n = 94)	53 (56.4%)	16 (17.0%)	12 (12.8%)	13 (13.8%)
Semester B (n = 71)	34 (47.9%)	21 (29.6%)	11 (15.5%)	5 (7.0%)
Two-semester total (n = 165)	87 (52.7%)	37 (22.4%)	23 (13.9%)	18 (10.9%)

major. The majority of the students were either from the Department of Mechanical and Aerospace Engineering (52.7%) or from the Department of Civil and Environmental Engineering (22.4%). A small percentage (13.9%) of students were from the Department of Biological Engineering.

### 3.2 Research method and data collection

Over the course of the semester, each student generated independently eight concept maps, with each map corresponding to one topic (i.e., one textbook chapter). After each textbook chapter was learned, students developed their own concept maps and submitted their finished maps to the instructor. The instructor reviewed and assessed their maps, and then selected and sent one or two best maps to all other students in the class, so each student could compare his/her own map with the best maps and learn from the best maps. During the lecture, the instructor further explained the strengths of those maps and described how those maps can be improved.

At the end of the semester, students were asked to respond to a questionnaire survey to describe their experiences with concept mapping, both positive and negative. The questionnaire survey included both Likert-type and open-response items. The following paragraphs list four survey items analysed in the present study.

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: Overall, the concept maps helped improve your skills in solving dynamics problems (that is, eventually reaching a numerical, quantitative solution to dynamics problems): (A) Strongly disagree, (B) Disagree, (C) Neutral, (D) Agree, (E) Strongly agree.

Item #4: 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.

Item #1 addresses overall student experiences with concept mapping. Items #2 and #3 examine whether concept mapping helped students improve their conceptual understanding and problem solving, respectively. Content analysis, one of qualitative research methods [26], was employed to analyze the qualitative data collected through survey item #4. The analysis involved coding (i.e., categorizing)

the collected data and then counting the frequency of a particular code. No commercial qualitative software was employed to code the data. Instead, the researchers of the presented study created their own Excel spreadsheet to code all the data. The coding process was time consuming because it was an iterative process and involved a significant amount of data, starting from an initial list of codes that categorized major themes that the data represented. As the coding process continued, the initial list of codes was modified by adding more codes (i.e., categories) to the list, or deleting one or several initial codes, or by combining two or several initial codes into one code. In other words, the final list of codes was not determined until the analysis of all the collected data was completed.

## 4. Results and analysis

### 4.1 Representative concept maps generated by students

Figures 2 and 3 show two representative examples of concept maps generated by students. The concept map in Fig. 2 shows how two important concepts, the Principle of Angular Impulse and Angular Momentum and the Conservation of Angular Momentum, are connected. The map also includes a set of mathematical formulas and a problem-solving procedure; for example, the mathematical formulas for angular impulse and angular momentum as well as the three-step procedure for solving problems using the Principle of Angular Impulse and Angular Momentum.

The concept map in Fig. 3 shows three important methods used for analyzing general plane motion: instantaneous center of zero velocity, absolute motion analysis, and relative motion analysis. For the method of instantaneous center of zero velocity, the map includes an example figure to show how to determine the instantaneous center. The map also includes a set of mathematical formulas to calculate relevant variables, such as velocity, relative velocity, acceleration, and relative acceleration.

Since the inception of concept mapping technique, various theories have been proposed to study what types of knowledge can be represented on a concept map. For example, in their recent study, Sharif Ullah, Rashid, and Tamaki [27] discussed two types of knowledge: analytic a priori knowledge (i.e., concepts that are true by definition) and synthetic a posteriori knowledge (i.e., relations of ideas or knowledge gained by rearranging the analytic a priori knowledge). In the present study, the author's observations on student-generated concept maps show that some students incorporated these two types of knowledge on their concept

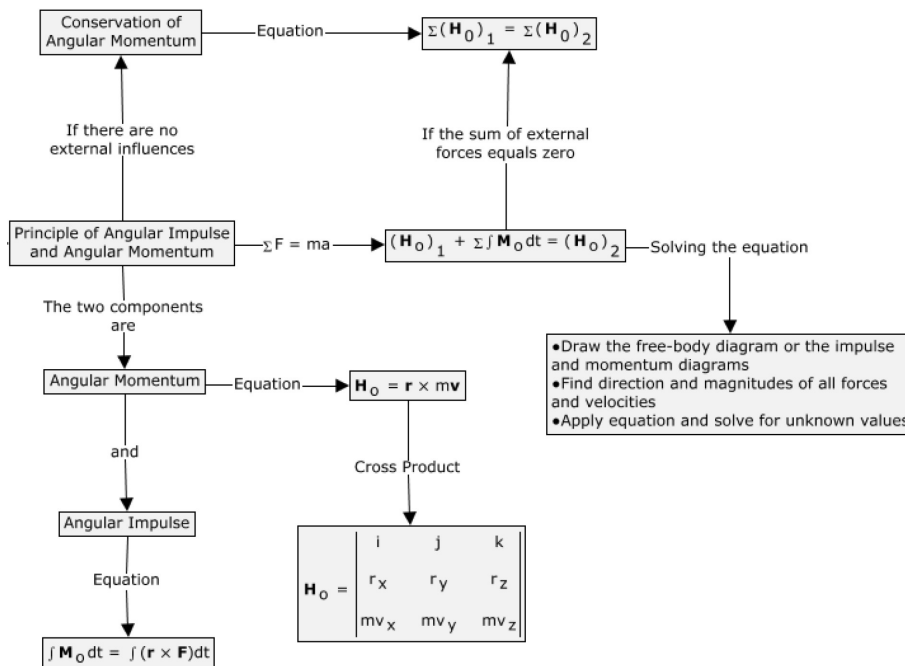


Fig. 2. The except of a student-generated concept map on the learning topic of “Kinetics of a Particle: Impulse and Momentum.”

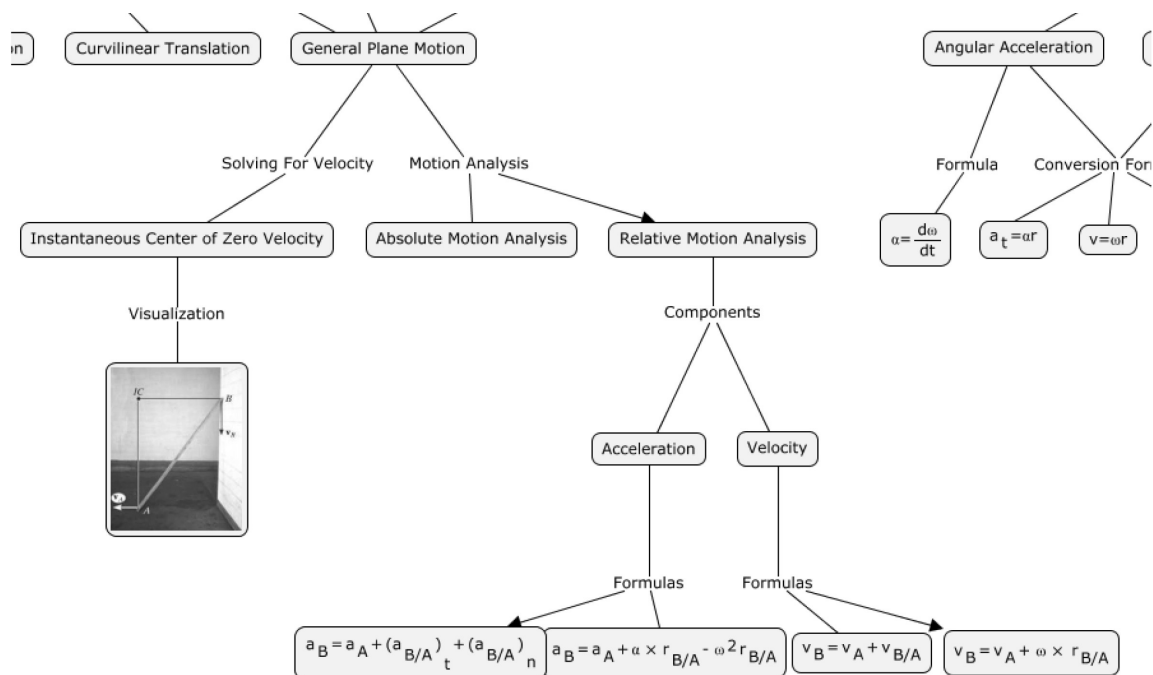


Fig. 3. The except of a student-generated concept map on the learning topic of “Planar Kinematics of a Rigid Body.”

maps. For instance, when arranging three related and easily confusing concepts, “angular momentum vector,” “linear momentum vector,” and “position vector” in different orders on his concept map, a student showed that different orders made a difference. The cross product of “position vector” and “linear momentum vector” leads to a positive “angular momentum vector.” However, the cross product of “linear momentum vector” and “posi-

tion vector” results in an opposite (negative) “angular momentum vector.”

#### 4.2 Overall student experiences with concept mapping

Figures 4–6 show the results of student responses to the first three Likert-type survey items in Semester A (n = 94), Semester B (n = 71), and two-semester total.

As seen from Figs. 4–6, 37% of the 165 students surveyed in the two semesters rated their overall experiences with concept mapping as “positive” or “highly positive,” 44% of the students “agreed” or “strongly agreed” that concept mapping improved their conceptual understanding of dynamics concepts, laws, and principles as well as their relationships, and 27% of the students “agreed” or “strongly agreed” that concept mapping improved

their problem solving skills in engineering dynamics. Although these percentage numbers are not significantly high, they represented an overall positive experience for many students.

The comparison between the results of Figs. 5 and 6 further reveals that students thought concept mapping was more helpful for improving concept mapping than for improving their problem solving. In engineering dynamics, a solid

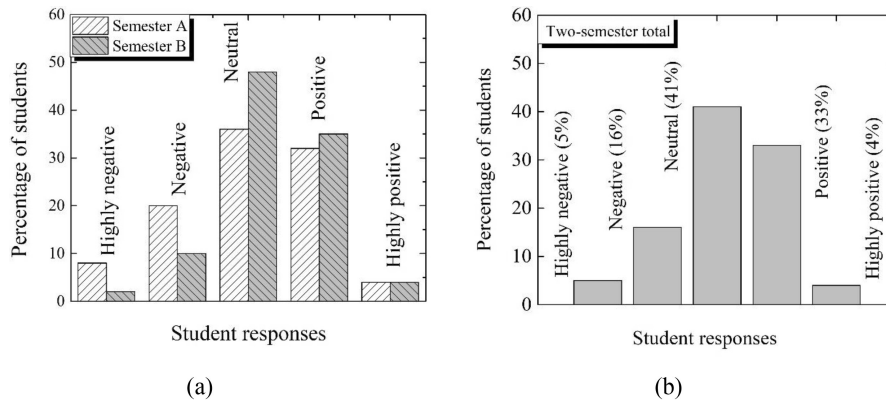


Fig. 4. Student responses to survey item #1 in (a) Semester A (n = 94) and Semester B (n = 71), respectively, and (b) two-semester total (n = 165).

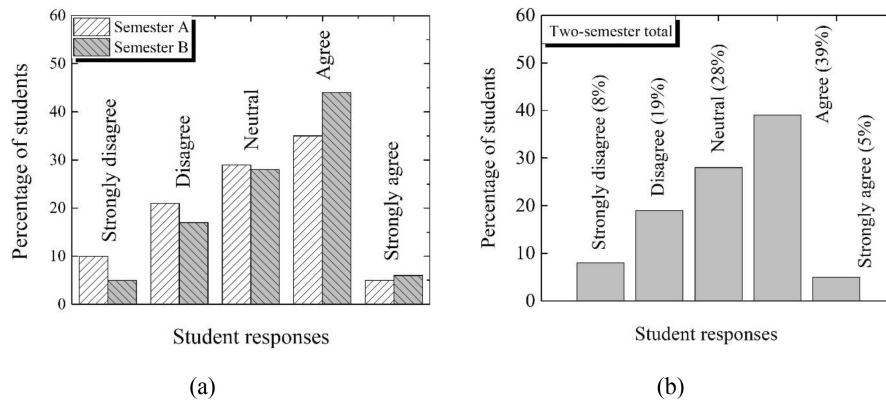


Fig. 5. Student responses to survey item #2 in (a) Semester A (n = 94) and Semester B (n = 71), respectively, and (b) two-semester total (n = 165).

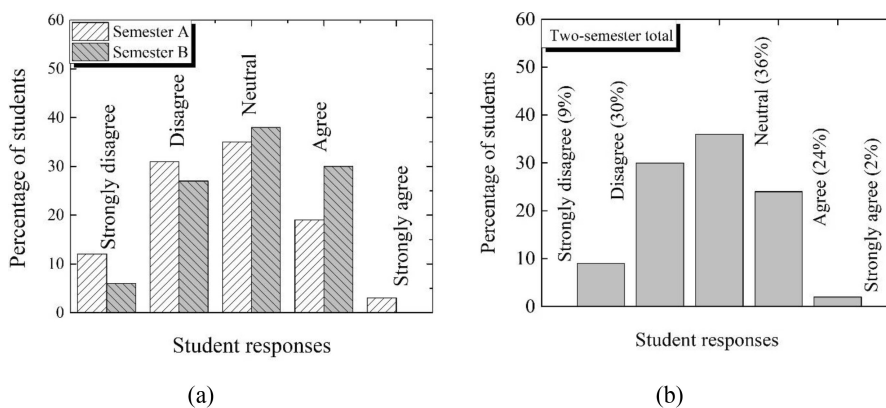


Fig. 6. Student responses to survey item #3 in (a) Semester A (n = 94) and Semester B (n = 71), respectively, and (b) two-semester total (n = 165).

conceptual understanding is an essential prerequisite (but not the only prerequisite) for students to successfully solve many problems [2, 3]. Many problems cannot be solved if a student does not understand key concepts involved in the problems. Nevertheless, many other factors, such as students' mathematical skills, abstract thinking skills, logic reasoning skills, and spatial skills, also play an equally important role in successful problem solving [5–7, 10, 28, 29].

For example, if a student is given a rigid-body kinetics problem that involves the application of Newton's second law, the student must first understand key concepts involved in the problem, such as force, acceleration, and general plane motion. However, it is insufficient for the student to solve the problem by understanding force, acceleration, and general plane motion concepts only. The student must also be able to draw a correct free-body diagram and a correct kinetic diagram, must be able to set up a correct mathematical equation using Newton's second law, and must be able to correctly solve the equation using his/her mathematical skills in calculus and/or algebra. Without necessary procedural knowledge, the problem cannot be eventually solved. Therefore, it can be reasonably concluded that although concept mapping is a powerful technique for improving student conceptual understanding, it is not a universal technique that can remove all obstacles to student learning. Other instructional interventions, such as computer simulation and animation, multimedia, and hands-on demonstrations and experiments [5–7, 10, 11], are also needed in order to improve student learning and problem solving in engineering dynamics.

### 4.3 Positive student experiences with concept mapping

Based on content analysis of students' open responses to survey item #4, students had positive experiences with concept mapping in seven categories, as summarized in Table 2. A representative example of student comments for each category is listed in the following paragraphs.

1. Helped make connections between concepts (frequency 69): "I think that drawing the lines connecting the different concepts helps me figure out which concepts can be related to each other and then which concepts are broader that encompass those more generalized concepts as well. So I can see the 'grandpa' all the way down to the smaller things."
2. Helped review what students had learned (frequency 32): "I liked it because it helped me look over the material and pick out the most important parts of it so that I could study more effectively."
3. Helped visualize concepts (frequency 25): "I liked the visual connections in seeing how the principles of dynamics tie together. I think seeing the big picture really helped with understanding the relationships and how they could be used to know which equations to use in solving the problems."
4. Helped understand concepts (frequency 23): "It mostly helped with connecting concepts. If I could understand one concept and also understand how it connected to a new concept through the concept maps I could understand the new concept."
5. Helped organize concepts (frequency 13): "I found it useful to organize the many different concepts that we've learned. There appears to be complicated equations but when looking at the concept maps, I can trace back to a simple fundamental concept."
6. Helped see the bigger picture of dynamics (frequency 13): "By forcing me to create relationships between the concepts it helps fill in the blanks of the big picture of the concepts. Also by having an idea of how the concepts are linked solidifies memory of how to use concepts together to solve problems."
7. Helped think more clearly about concepts (frequency 9): "In general, I believe that the concept maps were another opportunity to think about the material which had been covered in the chapter, and to think about it in a slightly different way. As opposed to working pro-

**Table 2.** Positive student experiences

Category	Frequency		
	Semester A	Semester B	Two-semester total
1. Helped make connections between concepts	37	32	69
2. Helped review what students had learned	9	23	32
3. Helped visualize concepts	11	14	25
4. Helped understand concepts	13	10	23
5. Helped organize concepts	4	9	13
6. Helped see the bigger picture of dynamics	6	7	13
7. Helped think more clearly about concepts	7	2	9

blems, where it is tempting and quite easy to focus narrowly on the immediate details of the specific problem, the concept maps encouraged me to think of the principles behind the solutions that I worked on.”

In terms of the frequency of codes, the top two reasons that students liked concept mapping are: (1) helped make connections between concepts (frequency 69) and (2) helped review what students had learned (frequency 32). These two reasons are expected as the purpose of concept mapping is precisely to help students see how a variety of concepts are connected, so as to enable students to see a bigger picture. Engineering dynamics covers many concepts. Most often, the knowledge on a topic is often built upon the knowledge on a previous topic students learned. Without seeing the bigger picture, students can easily get lost during the process of learning.

4.4 Negative student experiences with concept mapping

Table 3 summarizes the research findings about negative student experiences with concept mapping in four categories. The research findings were also based on content analysis of students’ open responses to survey item #4. A representative example of student comments for each category is listed in the following paragraphs.

1. Was busy work (frequency 19): “They were a lot of busy work. They impaired the time I had to work on the actual problems which help me understand the concepts.”
2. Did not help in understanding concepts (frequency 18): “I didn’t see any improvement on helping me understand the concepts. It just took up time having to figure out what to write down to draw up the map.”
3. Students had other ways to learn concepts (frequency 5): “To me, the concept map was not helpful. I learn best from constant examples and the concept maps were too hypothetical for my learning style.”
4. Was a small percentage of credit of the final course grade (frequency 3): “There was no incentive to complete concept maps. 1% is not

enough for me to spend time completing the concept maps properly.”

In terms of the frequency of codes, the top two reasons that students disliked concept mapping are: (1) was busy work (frequency 19) and (2) did not help in understanding concepts (frequency 18). It is interesting to note that in the previous section describing positive student experiences, students expressed that concept mapping “helped understand concepts (frequency 23).” Evidently, different students have different perspectives on whether concept mapping helped them understand concepts.

In the author’s analysis, the extent to which concept mapping helps understand concepts depends on many factors, such as depth of student knowledge, time that students spend on developing their concept map, and the way in which how concepts are arranged on the map. For example, if a student spends a significant amount of time on concept mapping and gives a significant amount of consideration to the relationships between different concepts, they will develop a better understanding of relevant concepts. However, if a student does not spend as much time on concept mapping and pays less attention to how different concepts are related, the map they develop is often a very simple map with only a few concepts. In this latter case, concept mapping does not help the student at all.

5. Limitations of the present study

The present study has two primary limitations. First, all student participants were from one institution, a public research university in the U.S. Students at other institutions may have different experiences with concept mapping. Data will be collected from multiple instructors at multiple institutions in the future. Qualitative research will be conducted to study how students understand the relationships between different concepts in engineering dynamics.

Second, due to its scope, the present study does not include the comparison between an experimental and a control group to determine how concept mapping affects student learning. It would be interesting to see how students understand the relationships between different concepts with and without

Table 3. Negative student experiences

Category	Frequency		
	Semester A	Semester B	Two-semester total
1. Was busy work	10	9	19
2. Did not help in understanding concepts	12	6	18
3. Students had other ways to learn concepts	3	2	5
4. Was a small percentage of credit of the final course grade	0	3	3



using concept mapping. An experimental study involving experimental and control groups will be conducted in future work.

## 6. Concluding remarks

As a powerful graphical technique, concept mapping helps learners organize knowledge and visualize connections and relationships between relevant concepts. In the present study, the concept mapping technique has been employed in an engineering dynamics course and both positive and negative experiences of students were investigated. This helps the engineering education community develop a better understanding of both the strengths and limitations of concept mapping.

Based on research findings from a total of 165 undergraduates who participated in the present study, the top two reasons that students liked concept mapping are: (1) helped make connections between concepts (frequency 69) and (2) helped review what students had learned (frequency 32). The top two reasons that students disliked concept mapping are: (1) was busy work (frequency 19) and (2) did not help in understanding concepts (frequency 18). Some students thought that concept mapping helped them understand concepts (frequency 23). However, other students thought differently (frequency 18). This research finding implies that concept mapping, although powerful, is not a universal tool to solve all problems for all students. Alternative approaches need to be taken to help those students who do not learn significantly from concept mapping.

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