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Tree of Dynamics: A Modified Concept Mapping Approach to Improving Students' Conceptual Understanding in Engineering Dynamics*

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This paper presents a modified concept mapping approach, called the "Tree of Dynamics," in which the relationships among concepts are represented by "tree" structures including roots, trunks, branches, leaves, and fruits, instead of by using linking words or phrases, to enhance students' perception of the relationships among concepts and also to add fun to student learning. The modified approach was implemented in an Engineering Dynamics course that the author of this paper taught in a recent semester. A total of 76 undergraduate engineering students participated in hands-on active learning activities in which students constructed a series of "Trees of Dynamics" that focus on improving students' understanding of the relationship among seven key Dynamics laws/principles. Both qualitative and quantitative methods (including pre-test–post-test, correlation analysis, and questionnaire survey) were employed in assessing student learning outcomes. The results of assessments show that the average learning gain for all student participants was 64.2%. Compared with the average pre-test score, the average post-test score increased 1.45 standard deviations. Moderate correlation (r = 0.309, p = 0.029) existed between students' conceptual understanding (gained from "tree"-constructing activities) and their problem-solving skills (measured from exams in which students were required to apply mathematics to generate a numerical solution to Dynamics problems). A total of 71% of the surveyed students agreed or strongly agreed that the "Tree of Dynamics" helped them to understand the hierarchical relationships among dynamics principles and associated equations.

Keywords: concept mapping; "Tree of Dynamics"; active learning; conceptual understanding; engineering dynamics

1. Introduction

1.1 Challenges of students' conceptual learning in Engineering Dynamics

Engineering Dynamics is a high-enrollment and high-impact, core engineering course that nearly all students in mechanical, aerospace, civil, biological, and biomedical engineering programs are required to take. This sophomore-level course covers a broad spectrum of foundational concepts such as force, velocity, acceleration, work, energy, impulse, momentum, and vibration [1, 2]. The course provides an essential basis and fundamental building blocks for advanced studies in many subsequent courses, for example, Advanced Dynamics, Structural Mechanics, System Dynamics and Control, and Machine and Structural Design.

Nonetheless, Dynamics is widely regarded as one of the most difficult courses in which to succeed [3, 4]. In a recent survey conducted by the author of this paper, students were asked about their perspectives about Dynamics. More than 60% of the students surveyed used phrases such as "much harder than Statics," "extremely difficult," "very challenging," and "are afraid of it." Students often drop out of engineering because they fail Dynamics—the last pre-professional gateway course before entering a professional engineering program. Barrett et al. [5] reported that in the standard Fundamentals of Engineering examination in 2009, the national average score on the Dynamics exam was only 53%.

The lack of a solid understanding of Dynamics concepts is among the major causes of students performing poorly in Dynamics. For instance, students do not understand fundamental differences and relationships among difficult concepts [6]. As Cornwell [7] pointed out, "in many students' minds, the [Dynamics] course seemed to be a collection of mathematical manipulations or 'finding the right equation'." The negative consequences include the following, among others.

- Students do not know when and why to apply what concepts and associated equations.
- Students are satisfied if they get the numerical solution to a problem, but do not think deeper.
- Students cannot apply what they have learned from classroom lectures to new situations or new problems.

1.2 Concept mapping and its applications

In its well-known study of "How People Learn" [8], the National Research Council in the U.S.A. reported three key findings, two of which are: "To

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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" and "A 'metacognitive' approach to instruction can help students learn to take control of their own learning by defining learning goals and monitoring their progress in achieving them" [8]. Concept mapping—as a graphical tool for knowledge organization, representation, and elicitation—directly addresses these two key findings.

Concept mapping 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 [9]. 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 the relationships among concepts. Two or more concepts that are connected by linking words or phrases form a proposition (i.e., a meaningful statement). Figure 1 shows the structure and characteristics of concept maps [10].

Concept mapping was based on constructive learning theory that asserts "learners must actively construct their knowledge through testing concepts on prior knowledge, applying these concepts to new situations, and integrating concepts in prior experience" [11]. To develop a concept map that is both technically and logically correct, learners must understand each concept and the hierarchical relationships among concepts. Thus, the process of construing a concept map is also a process of constructing new knowledge and exploring the connection and interaction between old and new knowledge. This process involves not only high-level cognitive learning engagements (e.g. critical thinking and reflection) but also high-level metacognitive learning, i.e., learners being aware of and taking control of their own learning.

Educational research has confirmed the effectiveness of concept mapping in improving student learning [12–14]. For example, Nesbit and Adesope [15] conducted a meta-analysis of 55 experimental and quasi-experimental studies on concept mapping that involved 5,818 student participants at levels ranging from Grade 4 to post-secondary and across subject areas (for example, science, psychology, statistics, and nursing) and education settings. Their meta-analysis found that, in comparison with traditional learning activities such as reading text massages, attending lectures, and participating in class discussions, concept mapping is more effective in achieving knowledge retention and transfer. Nesbit and Adesope [15] attributed much of this benefit to greater learner engagement that was resulted from concept mapping.

Owing to its positive impacts on improving student achievement, concept mapping has been adopted in nearly every discipline ranging from science, technology, engineering, mathematics, psy-

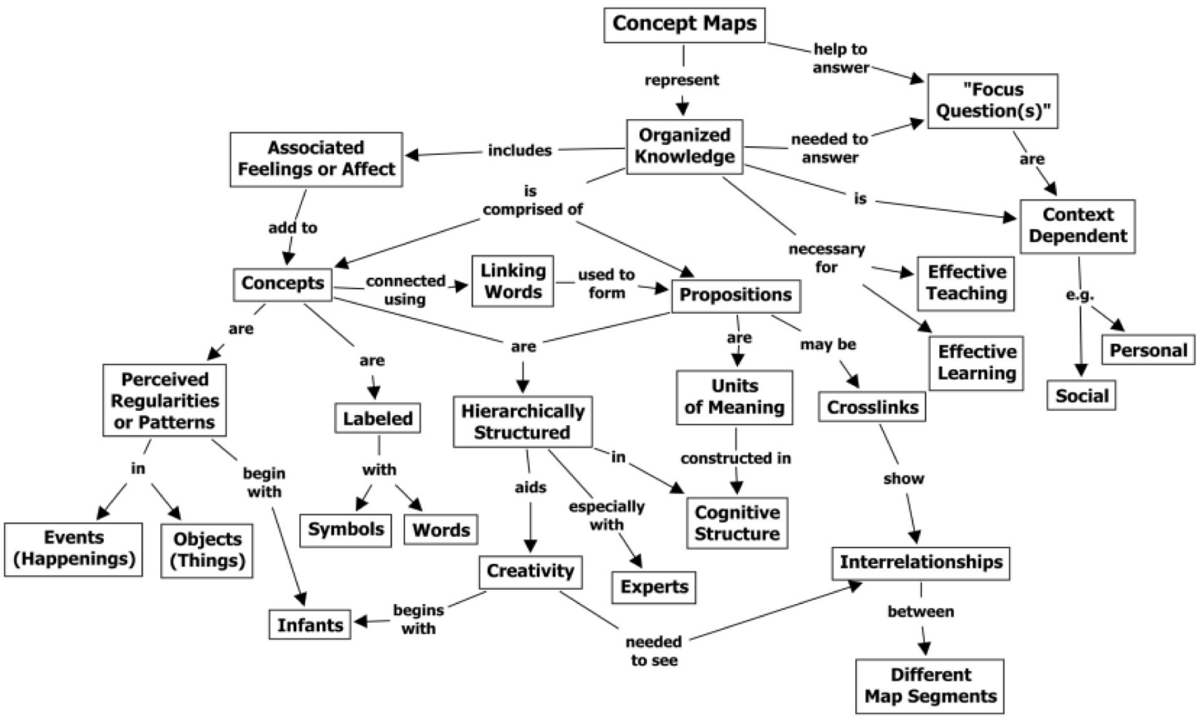

Fig. 1. The structure and characteristics of concept maps [10].

chology, and medicine to business, economics, accounting, history, and literature by institutions ranging from K-12 to undergraduate and graduate education [16, 17]. In recent years, concept mapping is receiving increasing attention in the engineering education community and has been applied in engineering courses such as Mechanics of Materials [18], Mechatronics [19], Engineering Design [20], and Aerodynamics [21]. Concept mapping has been employed in a variety of ways such as an instructional and learning strategy [20], a strategy for curriculum planning and development [22], and a tool for assessing student learning [17].

1.3 Innovation and uniqueness of the present study

Conventional concept maps include labeled nodes (in circles or boxes) to denote concepts or propositions. As shown in Fig. 1, linking words or phrases are used to connect concepts and indicate the relationships among concepts [9, 10]. Students learn the relationships among concepts through "reading" those linking words and phrases. Cognitively, this "learning by reading texts" activity might not be most effective. To enhance students' perception of those relationships among concepts and also add fun to learning, the present study undertakes a unique structure featuring a tree composition, that is, the relationships among concepts are represented by *"tree" structures including roots, trunks, branches, leaves, and fruits*, instead of by using linking words or phrases. For example, the foundation on which all concepts are built can be placed as the "root" of a tree. The main concept can be the "trunk." Concepts that derive from the main concept can be the "branches." These "tree" structures are collectively called the "Tree of Dynamics" because the present study focuses on developing concept maps for an Engineering Dynamics course. Two concrete examples of "Tree of Dynamics" will be provided in Section 2.2.

Presenting concepts using a "tree" is very visual and powerful because it makes the relationships among the concepts more easily understandable by students than in the traditional architecture of concept maps. Traditional concept mapping (see Fig. 1, for example) tends to yield maps that are crowed, cumbersome to read, and difficult to for the beginner to follow. However, teaching experience demonstrates that adding all possible relationships among concepts in a concept map overwhelms the beginner and loses him/her in a forest of details. The modified concept-mapping process that is proposed in this paper uses the tree as a topological framework for the architecture of the concept-mapping process. With roots, trunks, branches, leaves, and fruits, a "tree" is particularly helpful for students to see the "big picture" of dynamics, so students do not get lost. The "tree" also creates a gateway for students to explore a deeper understanding of course material, especially the fundamental relationships among various concepts, which are the basis of problem solving in dynamics.

The author of this paper has performed extensive literature review 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, the ASEE Annual Conference Proceedings (1995–2010), and the *ASEE/IEEE Frontier in Education Conference Proceedings* (1995–2010). No other literature was found that aims to develop a "Tree of Dynamics" for the Engineering Dynamics course, or to develop similar "tree" structures in any other engineering courses.

In addition, the results of the literature review showed that nearly all concept maps employed in teaching and learning Engineering Dynamics were developed by course instructors, who would then demonstrate their concept maps to students during classroom lectures [7, 23, 24]. For example, Cornwell [7] developed a concept map for the topic of particle kinematics. He set up his concept map on a corner of the classroom front wall. When he presented new materials, he would show their location in the concept map. Ellis et al. [23, 24] developed a course concept map and a dynamics concept map for a Continuum Mechanics I course. Their dynamics concept map focused on relating motion to its causes by Newton's Second Law and impulse–momentum relationship. Ellis et al. [23, 24] demonstrated their concept maps to students during classroom lectures.

In essence, demonstrations of concept maps during classroom lectures [7, 23, 24] is still a passive way of learning because students learn the relationships among concepts only through passive "watching and listening," not through active hands-on "doing." Cornwell [7] reported low scores on student evaluations of concept mapping conducted in this passive way, based on five evaluation criteria: problem solving, learning/comprehension, motivation/interest, problem visualization and intuition, and enjoyment. In the present study, the "Trees of Dynamics" were generated by students rather than by the instructor. Students learned to construct their own "trees" to represent the relationships among Dynamics concepts. This "tree"-constructing activity involves hands-on active learning that has been strongly advocated by extensive education research [25–27].

1.4 The overall objective of the present study and the contents of this paper

The overall objective of the present study is to improve students' conceptual learning in Engineering Dynamics through the modified concept mapping approach, i.e., the "Tree of Dynamics" approach. A detailed description of the modified approach is illustrated further with two example "trees" generated by students. Then, assessment methods are described, followed by an analysis of assessment results and discussions. Finally, conclusions are drawn at the end of this paper.

2. A modified concept mapping approach: the Tree of Dynamics

2.1 Construction of a "Tree of Dynamics"

In order to construct a technically correct and logically reasonable "tree," students must understand the hierarchical relationships among relevant concepts and be able to put concepts in correct positions on the tree, i.e., roots, trunks, branches, leaves, and fruits. In Engineering Dynamics, for example, both the "Principle of Work and Energy" and the "Principle of Impulse of Momentum" can be derived from Newton's Second Law. Thus, Newton's Second Law can be placed in the position of the trunk, while those two principles can be placed as two branches. Each branch can have its own sub-branches. The branch of "the Principle of Work and Energy" has a sub-branch of "Conservation of Energy" because the latter is a special case of the former. Therefore, instead of using linking words or phrases to indicate the relationships among relevant concepts (as in conventional concept mapping), the "tree" structure self-explains those relationships. Considering that students might use more than one form (such as trunk/branch, branch/sub-branch, branch/leave, and branch/fruit) to represent the relationships among those concepts, instructors can ask students to write a separate text to explain the "trees" that students have generated.

Students can construct a "tree" for each learning theme, such as each textbook chapter. A "tree" built for a new chapter can be integrated with the old "tree" that students have built for the previous chapter(s). As in conventional concept mapping, the process of constructing a "tree" is a process of learning from mistakes. Revisions and modifications are often necessary before a quality "tree" can be built. Collaborative learning among students and just-in-time (immediate) instructions by the instructor also play a significant role in helping students develop quality "trees."

2.2 Representative "Tree of Dynamics" generated by students

To illustrate what a "tree" may look like, Figs. 2 and 3 show two "Trees of Dynamics" generated by students in the Engineering Dynamics course that the author of this paper recently taught. The "tree" in Fig. 2 was generated by a two-student team, and the "tree" in Fig. 3 by an individual student.

The students who generated Fig. 2 took the initiative of adding artistic markers to their "tree." In the Word document accompanying the "tree," the students explained, "The roots are math and science. It then branches into two trunks, kinematics and kinetics. You will also see a knot in the upper right of the tree that represents the triangle of

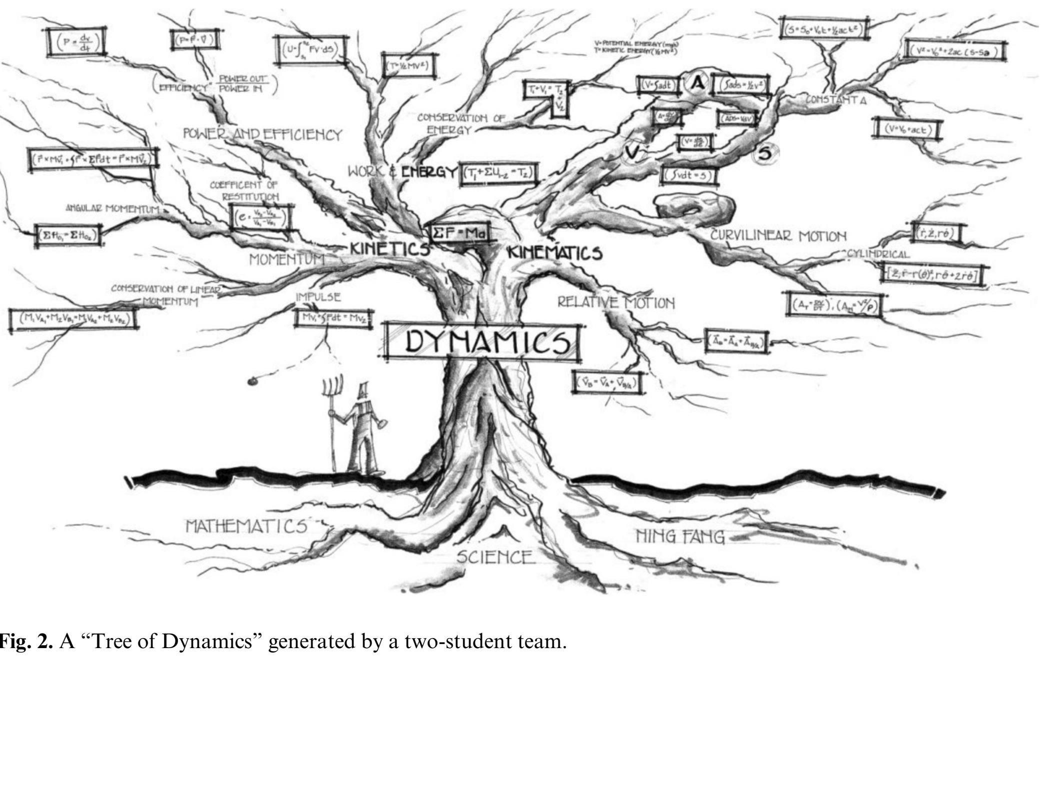

Fig. 2. A "Tree of Dynamics" generated by a two-student team.

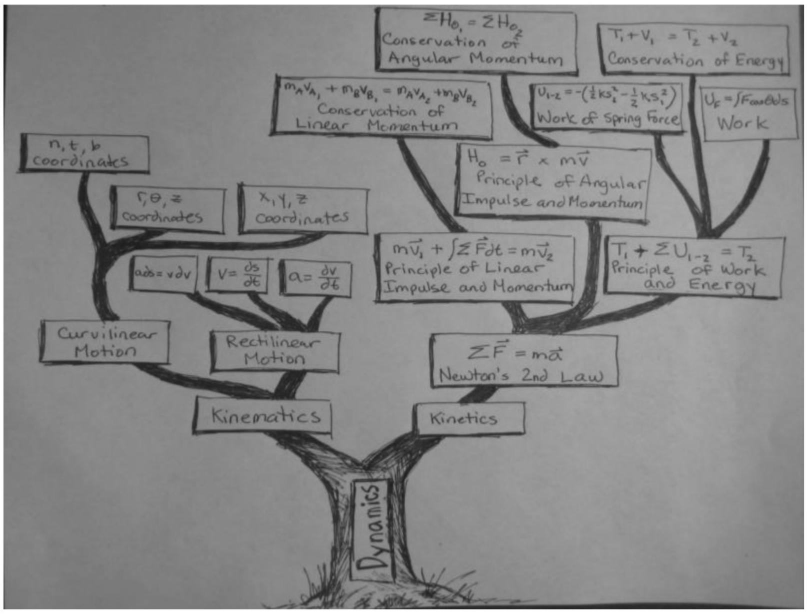

Fig. 3. Another "Tree of Dynamics" generated by an individual student.

kinematics. Newton's second law connects the two trunks. They then branch into the smaller aspects of dynamics, and the formulas and equations that you can derive from Newton's second law are shown in parenthesis. Our tree was drawn using artistic markers by my roommate who is a Landscape Architecture major."

The "tree" in Fig. 3 very clearly shows the relationships among important Dynamics concepts. In the Word document accompanying the "tree," the student explained, "The trunk of course is the main topic, Dynamics. Dynamics is then branched into two areas, kinematics and kinetics. Kinematics is branched into curvilinear motion and rectilinear motion. Curvilinear motion is branched off to the three coordinate systems that it involves which include the x, y, z, normal and tangential, and polar components. Rectilinear motion is branched off into the three main equations that create all the other equations of rectilinear motion. Kinetics has one continuing branch called Newton's Second Law. This branch creates three new equations/branches called the principle of linear impulse and momentum, principle of work and energy, and principle of angular impulse and momentum. The principle of linear impulse and momentum can then branch off to the conservation of linear momentum. Also, the principle of work and energy can be branched off into the general work equation, work of spring force, and the conservation of energy. The principle of angular impulse and momentum can be branched off to the conservation of angular momentum."

3. Assessment methods

3.1 Student participants and activities of constructing "trees"

A total of 76 students who took the Engineering Dynamics course from the author of this paper participated in the present study. Table 1 shows student demographics. As seen from Table 1, 59.2% of the students were mechanical and aerospace engineering majors, and 25.0% of the students were civil and environmental engineering majors. The vast majority of students was male (88.2%), while female students accounted for only 11.8%.

Students were asked to construct "Trees of Dynamics" that focus on improving students' understanding of the relationship among the following seven key Dynamics laws/principles:

- Newton's Second Law
- Principle of Work and Energy
- Conservation of Energy
- Principle of Linear Impulse and Momentum
- Conservation of Linear Momentum
- Principle of Angular Impulse and Momentum
- Conservation of Angular Momentum.

Of the 76 student participants, 35 students chose to work individually, and 41 students chose to work in 15 teams with two to four students on each team. Therefore, a total of 50 "trees" were generated, including 35 "trees" generated by individual students and 15 "trees" generated by student teams. To encourage creativity, students were allowed to add all relevant information that they thought appro-

Table 1. Student demographics

	Major*			**Sex**	
	MAE	**CEE**	**Other**	**Male**	**Female**
Total student participants (*n* = 76)	45 (59.2%)	19 (25.0%)	12 (15.8%)	67 (88.2%)	9 (11.8%)

* MAE:Mechanical and aerospace engineering.
CEE: Civil and environmental engineering.
Other: Biological engineering, general engineering, pre-engineering, undeclared majors, etc.

priate to their "trees." Each "tree" was then evaluated based on a set of scoring criteria developed by the instructor and shown in Table 2. To add fun to this hands-on active learning practice, all "trees" were entered for the final "Tree of Dynamics Contest." The top ten winners demonstrated and explained their "trees" in the final Award Ceremony, so they could share their experiences with the other students in the class.

3.2 Assessment methods

Both qualitative and quantitative methods were employed in the assessments that included the following three aspects.

1. *Students' conceptual learning gains*. Of the 76 student participants, 53 students chose to take a pre-test and a post-test that measured their conceptual understanding of the seven Dynamics laws/principles. Conceptual learning gains were calculated for each pre-test-post-test question for each student using the following formula [28]:

$$\text{Learning gain} = \frac{\text{Post-test score }(\%) - \text{Pretest score}(\%)}{100(\%) - \text{Pretest score}(\%)} \quad (1)$$

2. *Correlation between students' "tree scores" and exam scores*. In addition to participating in "tree"-constructing activities, those 53 students also took two exams that included 31 Dynamics problems. In the exams, students were required to apply mathematics to obtain a numerical answer to these problems. By examining the correlation between students' "tree scores" and exam scores, one can determine whether students' conceptual understanding (gained from "tree"-constructing activities) is statistically correlated with their problem-solving skills.
3. *Questionnaire survey that assessed students' experiences with the "Tree of Dynamics."* The survey was administrated at the end of semester and included both Likert-type and open-ended questions. All 76 students who participated in "tree"-constructing activities responded to the questionnaire survey.

4. Assessment results and analysis

4.1 Students' conceptual learning gains

A set of pre-test–post-test conceptual questions was developed to measure students' conceptual learning gains. The following paragraphs are example conceptual questions.

Table 2. Scoring criteria for student-generated "trees"

Scoring items	**Score**
The 'tree" shows two main branches of "Kinematics" and "Kinetics," or the "tree" shows that "kinematics" is the foundation (root) of "kinetics."	+1
The "tree" correctly shows the relationships among displacement, velocity, and acceleration.	+1
The "tree" correctly shows that all six Dynamics principles stem from Newton's Second Law.	+2
The "tree" correctly shows four hierarchal relationships:	
• Between the "Principle of Work and Energy" and the "Principle of Conservation of Energy."	+1
• Between the "Principle of Linear Impulse and Momentum" and the "Principle of Conservation of Linear Momentum."	+1
• Between the "Principle of Linear Impulse and Momentum" and the "Principle of Angular Impulse and Momentum."	+1
• Between the "Principle of Angular Impulse and Momentum" and the "Principle of Conservation of Angular Momentum."	+1
The structure of the "tree":	
• The "tree" shows only some (not all) hierarchal relationships among Dynamics concepts, or	–1, or
• The "tree" does not clearly show the hierarchal relationships among Dynamics concepts at all.	–2
The number of technical errors (regarding the hierarchal relationships among Dynamics concepts) contained in the "tree":	
• 1–2 errors, or	–1, or
• 3–4 errors, or	–2, or
• 5 or more errors	–3

Conceptual question #1: Who is a "grandparent" from which all other law/principles can be derived?

(A) Principle of work and energy
(B) Conservation of energy
(C) Principle of linear impulse and momentum
(D) Newton's Second Law
(E) I do not think that a "grandparent" exists.

Conceptual question #2: "Conservation of Linear Momentum" is the immediate descendant of

(A) Newton's Second Law
(B) Principle of work and energy
(C) Conservation of energy
(D) Principle of linear impulse and momentum
(E) Principle of angular impulse and momentum.

Conceptual question #3: Which of the following statements is true?

(A) "Principle of Work and Energy" can be derived from "Conservation of Energy."
(B) "Principle of Linear Impulse and Momentum" can be derived from "Conservation of Linear Momentum."
(C) "Principle of Angular Impulse and Momentum" can be derived from "Conservation of Angular Momentum."
(D) "Principle of Angular Impulse and Momentum" can be derived from "Principle of Linear Impulse and Momentum."
(E) None of the above statements is true.

Figures 4, 5, and 6 show student responses to conceptual questions #1, #2, and #3, respectively. As can be seen clearly from these figures, significant learning gains were achieved for question #2, which assesses students' understanding of the relationship between "Conservation of Linear Momentum" and "Principle of Linear Impulse and Momentum." Moderate learning gains were achieved for question #3. Students' learning gains for question #1 was insignificant due to the high pre-test scores of students, which implies that question #1 is an easy question and that no education intervention is necessary in order to help students correctly answer question #1.

The average pre-test score and post-test score were calculated for all students on all pre-test–post-test questions. Equation (1) was then used to calculate the average learning gain. The calculation results showed that for all students on all questions, the average pretest score is 54.1%, and the average post-test score was 83.6%. Based on Equation (1), the average learning gain for all student participants on all questions was 64.2%. Compared with the average pretest score, the average post-test score increased 1.45 standard deviations. These two num-

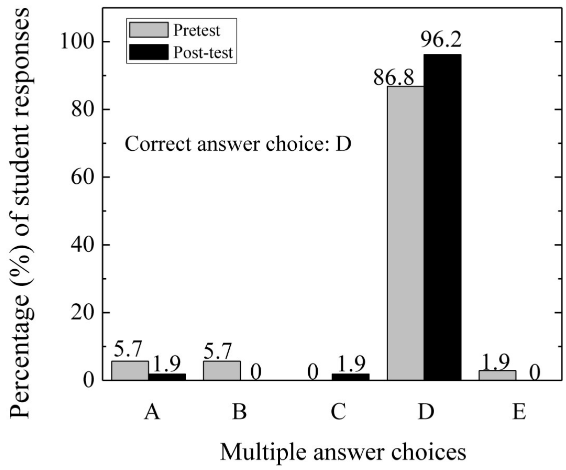

Fig. 4. Student responses to conceptual question #1 in the pre-test–post-test.

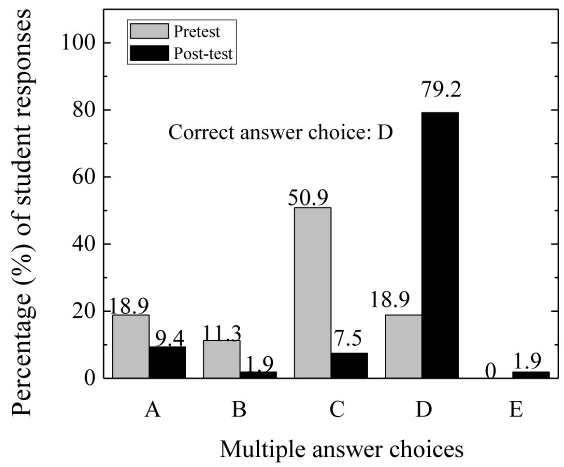

Fig. 5. Student responses to conceptual question #2 in the pre-test–post-test.

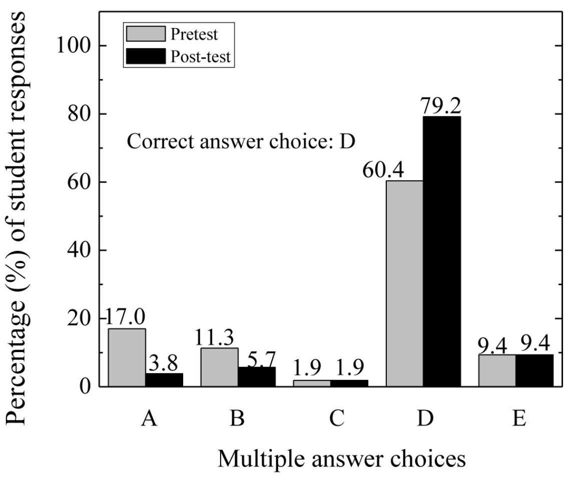

Fig. 6. Student responses to conceptual question #3 in the pre-test–post-test.

bers (64.2% and 1.45) validate the effectiveness of the "Tree of Dynamics" in improving students' conceptual understanding in Dynamics.

4.2 Correlation between students' "tree scores" and exam scores

Statistical correlation analysis [29, 30] was performed between students' "tree" scores and their exam scores. The results showed that the Pearson correlation coefficient $r = 0.309$ with $p = 0.029$ (< 0.05). Therefore, moderate correlation existed between student's "tree" scores and their exam scores or, in other words, between students' conceptual understanding (gained from "tree"-constructing activities) and their problem-solving skills.

4.3 Students' experiences with the "Tree of Dynamics"

The questionnaire survey included both Likert-type and open-ended questions. The Likert-type question is:

Please rate the following statement: The "Tree of Dynamics" helped me understand the hierarchical relationships among dynamics principles and associated equations.

(A) Strongly disagree
(B) Disagree
(C) Neutral
(D) Agree
(E) Strongly agree

Figure 7 shows student responses to the above question. A total of 71% of the students agreed or strongly agreed that the "Tree of Dynamics" helped them to understand the hierarchical relationships among dynamics principles and associated equations.

The majority of the students indicated they had a positive experience with the "Tree of Dynamics." Representative student comments are listed in the appendix.

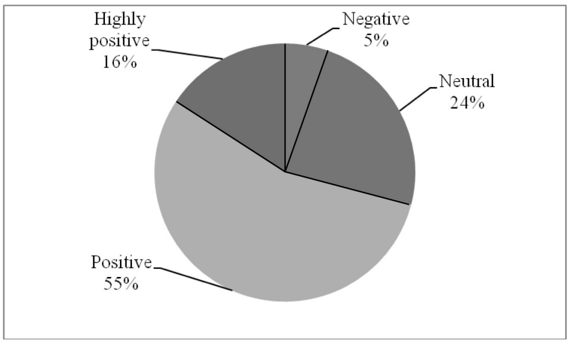

Fig. 7. Student responses to the survey question.

5. Discussions

In the present study, a total of 76 undergraduate engineering students participated in hands-on active learning activities in which they constructed "Trees of Dynamics" that focus on improving students' understanding of the relationship among seven key Dynamics laws/principles. Both qualitative and quantitative methods (including pre-test–post-test, correlation analysis, and questionnaire survey) were employed in assessing student learning outcomes. The assessment results validate the effectiveness of the modified concept-mapping architecture (i.e., the "tree" architecture) in enhancing student learning.

However, it should be pointed out that the modified concept-mapping architecture is achieved at a cost. The cost is that some relationships among concepts are hidden (but not eliminated) because tree branches do not directly relate to each other, except through the trunk. For example, kinetics and kinematics are two essential components of dynamics. They can be placed as two branches on a "tree." In reality, however, the solution of dynamics problems often requires relating kinetics and kinematics. That interaction is lost in the "tree" structure. This is the limitation of the present study.

Two lessons were learned from the present study. First, at the beginning of the semester, example "trees" should be provided to students to help them get started as early as possible. Many engineering students, such as those in the author's university, may not have previous experience of constructing concept maps or "trees." Example trees would be helpful to best prepare students for constructing their own "trees."

Second, the "tree" assignment should be given more weight in the final course grade. In the present study, some students confessed that they did not take the assignment very seriously because it accounted for only a small percentage of the final course grade. After the "Tree of Dynamics contest," some students admitted that they did not realize how helpful the "tree" was until they saw the other "trees" built by fellow students. Therefore, the construction of "Tree of Dynamics" is strongly suggested to be assigned as a semester-long project and carry more weight in the final course grade.

6. Conclusions

As a graphical tool for knowledge organization, representation, and elicitation, concept mapping involves not only high-level cognitive learning engagements (e.g. critical thinking and reflection) but also high-level meta-cognitive learning, i.e., learners being aware of and taking control of their own learning. This paper presents a modified concept mapping approach in which the relationships among concepts are represented by "tree" structures including roots, trunks, branches, leaves, and fruits, instead of by using linking words or phrases, to enhance students' perception of the relationships among concepts and also to add fun to student learning. The modified approach was implemented and assessed in an Engineering Dynamics course that the author of this paper recently taught. The assessment results show that:

1. The average learning gain for all student participants was 64.2%. Compared with the average pre-test score, the average post-test score increased 1.45 standard deviations.
2. Moderate correlation ($r = 0.309$, $p = 0.029$) existed between students' conceptual understanding (gained from "tree"-constructing activities) and their problem-solving skills.
3. A total of 71% of the surveyed students agreed or strongly agreed that the "Tree of Dynamics" helped them understand the hierarchical relationships among dynamics principles and associated equations. "Helped," "understand," and "equations" are three words most frequently used by students. The comprehensive assessments show that the "Tree of Dynamics" is effective in improving students' conceptual understanding in Engineering Dynamics.

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Appendix: representative student comments

- "I think the tree helped clarify the relationships between all the principles and created an easy visual organization of the relationships. I feel the tree helped me study for the test. I feel I better understand the physical meaning behind the equations and can therefore better use them because of the assignment. Doing the assignment was much better than looking at a tree."
- "It helped me learn how to apply special cases of the principles/equations that we can use. (For example, Conservation of Energy, Linear Momentum, or Angular Momentum). Having to physically organize it myself on paper helped a ton by forcing the organization to take place in my brain first."
- "The tree of dynamics helped me understand more fully how all aspects, principles, and theories of dynamics are inseparably connected to one another. It helped me understand this more clearly by providing a visible/ tangible example of how equations of dynamics are related."
- "It helped review everything we had learned, & better understand the relationships of the equations. I even took a tree with me on the exam."
- "I did not think that all of the questions were as related as they are. I, especially from seeing others' trees, really learned the thought process behind why they were created. I liked it."
- "It helped me to organize what we have learned into a logical way of approaching problem. I enjoyed it a lot. I am a visual learner and this activity gives me a visual approach."
- "It was good to see all of the principles and equations on one sheet of paper. The tree allowed me to see how each one was related and made them easier to understand, remember, and apply."
- "By doing the tree of Dynamics it helped me to better understand how each equation is derived. As well after we have covered previous chapters it helped to review them and see how our foundation was built."
- "The tree of dynamics helped me see how everything was related. It helped me organize everything we learned in a meaningful way."
- "The tree of dynamics helped me see how everything was related. It helped me organize everything we learned in a meaningful way."
- "I can tell this is really helpful for connecting all dynamics concepts. It lets me know dynamics is just the basis concept of Newton's Second Law. Everything can be derived from that."
- "It helped because it was not just equations being pushed together but it draws relationships for standardizing approaches."
- "It helped because it makes you go look and see where each equation comes from, and it helped organizing it so you can see where each equation comes from and is placed in comparison to other equations."
- "This experience helped me to think about how things are connected and how we get our formulas."
- "It helped to understand the relationships because the different equations. This way we don't just have a bunch of equations without knowing where they come from."

Ning Fang is an Associate Professor in the College of Engineering at Utah State University, U.S.A. He has taught a variety of engineering courses such as engineering dynamics, metal machining, and design for manufacturing. His areas of interest include computer-assisted instructional technology, curricular reform in engineering education, the modeling and optimization of manufacturing processes, and lean product design. He has Ph.D., MS, and BS degrees in mechanical engineering and is the author of more than 60 technical papers published in refereed international journals and conference proceedings. He is a Senior Member of the Society for Manufacturing Engineering and a member of the American Society of Mechanical Engineers. He is also a member of the American Society for Engineering Education and a member of the American Educational Research Association.