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Using Concept Maps to Enhance Understanding in Engineering Education*

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Research has shown that students often have difficulty seeing the 'big picture.' Because they do not organize their knowledge in a way that facilitates understanding, retrieval and application, they are often unable to apply their knowledge to situations differing from those studied in class. Concept maps are pedagogical tools that help students structure their learning in useful ways. This paper presents the use of concept maps for meaningful learning in engineering. Our intent is to provide a rationale and explain the pedagogical approach underlying our use of concept maps. A distinctive aspect of our use of maps is that rather than being a tool for teaching, concept maps are tools that students use to support learning. Two maps developed for Continuum Mechanics I, a sophomore-level engineering course in the Picker Engineering Program at Smith College, illustrate their application. In this course concept maps were used extensively to communicate ideas, help students see the relationships among concepts, solve problems, and support project work. Student assessment data indicate the effectiveness of this approach in the classroom.

INTRODUCTION

THE PICKER ENGINEERING PROGRAM at Smith College is the first undergraduate program leading to an engineering degree at a woman's liberal arts college. The foundation and rationale for the program conceives of engineering as connecting basic scientific and mathematical principles in the service of humanity. Thus imagined, engineering finds itself well situated at a liberal arts college. Moreover women have not been adequately represented in the field of engineering and the program at Smith College will help remedy this. The engineering program's goal is to educate engineers who are adaptable to the rapidly changing demands of society, preparing them to lead society toward an equitable and sustainable future [1].

The engineering faculty members realize that establishing this program and achieving these ambitious goals will require substantial innovations in pedagogy and curriculum. Engineering and education faculty have been collaborating in developing, testing, and refining the use of various pedagogical tools. This paper presents the use of concept maps as one such tool to enhance learning. In the work presented here, several types of concept maps are employed in several different ways but always to provide explicit focus on the structure and interrelationships among ideas. We begin with a preamble explaining this theoretical rationale.

Any pedagogical innovation adopted by the engineering faculty must share several goals and chief among these is that the learning be meaningful rather than rote. Too often engineering education has been organized around the teaching and learning of procedures to be applied to solving particular classes of problems. The pedagogy practiced in engineering courses typically takes a 'bottom-up' approach, adding incremental bits and pieces as students tackle increasingly difficult problems. The hope is that students will eventually get the big picture and be able to integrate and apply all the procedures. The all-too-frequent reality, however, is that students cannot transfer knowledge. This becomes evident when they are unable to solve problems even slightly different from those used for practice and instruction. The lack of transfer is even more apparent across courses. This narrowness of learning and lack of transfer is a widely recognized problem in engineering education and is eloquently expressed by Schneck [2 (p. 213)]:

> The exponential surge of material that must now be covered in engineering curricula, its rapid obsolescence, and the general trend toward more holistic attitudes in 21st century education, all require that the engineer of the future be a product of a program of integrated learning—one that teaches students to use unified, deductive approaches to the creative formulation and solution to engineering problems. Moreover, successful engineering programs in the 21st-century university will be those that address the current void between product-oriented skills training, and process-oriented holistic training. That is, as engineering educators we spend considerable time teaching skills—'how to' techniques for applying the laws of physics; 'cook-book' approaches for formulating and solving specific types of problems; 'methods' for integrating, differentiating, using vector and tensor algebra; computer 'literacy;' inductive reasoning—and we do so with our own individual bias, our own approach (within the framework of a course syllabus), and our own perception of what we think

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the student is learning. Rarely, if ever, do we concern ourselves with the process of education, the long-term effectiveness of our efforts. . .

Much of the literature of cognitive science, particularly as it is applied to instructional psychology, agrees on the basic requirements for meaningful learning to take place. These are well summarized by Novak [3 (p. 19)]:

1. *Relevant prior knowledge:* that is, the learner must know some information that relates to the new information to be learned in some nontrivial way.
2. *Meaningful material:* that is, the knowledge to be learned must be relevant to other knowledge and must contain significant concepts and propositions.
3. *The learner must choose to learn meaningfully:* that is, the learner must consciously and deliberately choose to relate new knowledge to knowledge the learner already possesses in some nontrivial way.

The third of these three requirements focuses on what the learner must do in order to learn meaningfully. Clearly, intentionality on the part of the learner is crucial. Even with the best of intentions, learners need to know how to process information in ways that enable them to construct meaningful knowledge. Mayer describes three processes in which the learner must engage for meaningful learning to take place [4]. These are: select, organize, and integrate. Learners must recognize and pay attention to the relevant and important content, they must organize the content in a structure that is faithful to the disciplinary structure of the content, and they must integrate the content into their existing cognitive structure (i.e., knowledge).

Stepping back from this extremely brief overview of meaningful learning, it is evident that the instructional role of the teacher is very important, but perhaps more important is the role of the learner. For no matter what the instructor does, meaningful learning cannot take place if the learner lacks the prior knowledge, the intention, and/or the requisite learning skills.

This is not to diminish the challenges of designing effective pedagogical practices. Assessing students' existing knowledge, providing quality content that is structured so as to be potentially meaningful, using assessment strategies that hold students accountable for meaningful rather than rote learning, creating a learning community that encourages learners to intend to learn meaningfully, and finally providing skills and tools that will assist learners in structuring and integrating content—these are all part of the teacher's responsibilities. The faculty members in Smith's engineering program are working on numerous pedagogical fronts. The aspects of teaching that are highlighted in this paper are those that are aimed at assisting learners to assume responsibility for their own learning.

We consider many of the most important learner strategies (in contrast to teacher strategies) to be largely metacognitive in nature. By metacognitive we mean strategies that are eventually initiated by the learner and that are directed at self-monitoring and self-regulation. Theory directs us to believe that the best way to teach metacognitive strategies is to first model their use explicitly and then, in a variety of ways, encourage students to internalize the strategies. A metacognitive approach to disciplinary instruction has been demonstrated to result in more permanent restructuring of knowledge, better retention and improved understanding over time [5]. Achieving self-monitoring and self-regulation requires not only learner intention but also a repertoire of learning skills that can be brought to bear appropriately and effectively in a learning situation. Mayer identifies two classes of strategies that learners can use to facilitate meaningful learning. One he calls structure strategies [6]. These strategies help learners think about the structure of the content they are learning. They acquire an organized and inter-related set of ideas, a set that they can continue to build upon rather than a hodge-podge of unconnected facts and formulae. The second class of strategy Mayer calls generative. Generative strategies help learners link new knowledge with existing knowledge. These strategies focus on productive ways of processing information, ways that involve the sort of intentions and consciousness necessary for meaningful learning. This paper reports on the use of concept maps as a tool to facilitate the use of effective structure strategies on the part of learners.

OVERVIEW OF CONCEPT MAPS

Concept maps are not a new phenomenon in education or in engineering education. The theory underlying their use stems largely from the work of Ausubel and subsequent work by Novak, and Novak and Gowin [7–10]. The theory stresses that meaningful learning is an effortful process involving the construction of relationships between the learner's existing knowledge and new knowledge. This, of course, sounds deceptively simple. Not all effort on the part of the learner is equally productive. And as anyone who has taught science and engineering knows, the learner's existing knowledge often contains deeply rooted misconceptions that make new learning difficult. The use of concept maps holds promise in that they make issues of knowledge, knowledge structure, and the way ideas are related explicit and the subject of group discourse.

Concept mapping has been used in a wide variety of ways. Considerable work has been done using concept maps as an assessment device [11–13]. While promising as an assessment tool, a thoughtful article by Ruiz-Primo and Shavelson urges caution in using maps for assessment until further validity studies are done [14]. Maps have been used effectively as planning tools by Starr and Krajcik and Posner and Rudnitsky [15, 16]. Pankratius has used maps to teach problem solving in a high school physics unit on conservation of energy and momentum. He found that while direct instruction of problem solving was not successful, the group who learned to use concept maps developed significantly better problem-solving skills. Pankratius believed that the concept map group developed a more organized knowledge base like that developed and used effectively by expert problem solvers [17].

Wandersee explores the metaphor of a map as applied to concept mapping and likens map-making to theory building. He finds concept maps a useful tool in supporting meaningful learning. A concept 'mapper' must transform knowledge, identify key concepts, and relate them to each other in a meaningful way. Wandersee believes that mapping and knowing are closely intertwined; that maps are excellent heuristic devices; that changes in maps reflect changes in understanding; and that maps have great cognitive, integrative, summative, and generative power [18].

Smith argues for the importance of helping (engineering) students understand the nature and structure of knowledge and also how humans learn if (the student's) learning is to be meaningful [19]. He finds concept mapping a worthwhile heuristic for helping experts make their own understanding more evident to learners and for helping learners better understand the structure of knowledge. McAleese finds that using concept maps predisposes learners to consider and make relationships among concepts [20].

Conceptual mapping as implemented in this study has two major purposes. One is to help students gain and maintain an understanding of the overall conceptual structure of the course and, even more broadly, to see how and where the ideas in this course relate to other aspects of the engineering curriculum. The point is to help students avoid the sort of tunnel vision that can occur as students work on specific course tasks but never develop a meaningful conception of what the course is about. A second purpose of concept maps in this course is to help students become better problem solvers. A second, more focused map is used to help students organize their thinking as they solve rigid body dynamics problems.

This study reports on how the maps were developed, used, and received by both students and the instructor in an engineering course. The techniques used to develop the maps highlight collaboration between the engineering instructor and a cognitive scientist. We also solicited student feedback during the course and made adjustments in the map if these seemed warranted. The instructor referred frequently to the map, modeled its use in his own problem solving and thinking about the course ideas.

CONTINUUM MECHANICS

Continuum Mechanics I, EGR 270, is a four-credit, semester-long course that is largely populated by sophomore engineering students. The aim of the course is for students to develop a strong conceptual understanding and problem-solving skills in a variety of topics related to the mechanical behavior of a continuum. Topics include 2-D and 3-D equilibrium, shear and bending moment diagrams, rigid body dynamics, vibrations, and an introduction to stress and strain.

The need for conceptual maps and narratives

Introductory engineering mechanics courses typically apply a few fundamental concepts (such as Newton's Laws) to a wide variety of mechanical systems. It is all too easy in such a course to teach students problem-solving procedures while either losing sight of how these procedures relate to the fundamental concepts or never really paying attention to the fundamental concepts in the first place. This type of teaching results in students who are unable to apply their knowledge outside of a limited domain of idealized situations; it also inhibits future learning because students do not organize their understanding of concepts in a way that will facilitate continued learning. In addition, it can be difficult for students to see how the content details fit together within the course, with other courses and with their own educational goals. EGR 270 is designed to help students see the big picture of how materials behave early in their engineering education. To help them achieve this goal, we have developed a course concept map that illustrates how the mechanical behavior of an object is related to the loading, material, and geometry of the object.

In addition to helping students structure how the major concepts in the course fit together, we have also found a need for them to think about the prerequisite knowledge that they bring to the course and how this knowledge is structured. Though a course in Newtonian mechanics is a prerequisite, students typically enter EGR 270 not having fully mastered the concepts in mechanics and thus often cannot apply them to unfamiliar situations. This is not surprising since many introductory physics textbooks treat Newtonian mechanics as a series of discrete topics with little emphasis on how the content is related. Thus students typically begin the study of engineering mechanics having seen and applied many topics in mechanics, but without seeing how the concepts and problem-solving procedures fit together. When confronted with the non-idealized, often messy, real-world problems that face engineers, they do not know how to proceed. In an attempt to address this, students were provided with a second conceptual map, referred to as the dynamics map, that complemented the course concept map. The purpose of this map is to help them organize the knowledge that they bring to the course and to provide a tool for applying that knowledge in problem solving. In this map the variables measuring linear and rotational motion are related to each other and to their causes. Because the map relates time-varying forces to time-varying motion, it helps students think beyond the equations of constant acceleration to more generalized motion.

The maps and the conceptual frameworks they represent

The course concept map initially used in EGR 270 is shown in Fig. 1. During the process of developing and using the map, two points relating to its effective use and construction became apparent. Representing the relationships among ideas by using a concept map necessarily results in some oversimplifications of the actual complex relationships. We have found that maps work best when they get increasingly sophisticated in ways that 'keep pace' with student learning. The right level of sophistication was identified through the extensive teacher/student interactions that the map facilitated. By beginning with a simpler version of the map and adding complexity, we reduced the initial intimidation that some students expressed at seeing the entire structure of a course represented at the beginning of the semester. The second point is that student input is essential for identifying map elements requiring clarification and further development, as well as providing feedback on the map's implementation in the classroom. The development of the map is an iterative procedure that is best accomplished in collaboration with individuals who are not necessarily subject matter experts. Experts often fail to realize the tacit knowledge that they possess and that must be represented in a map for students. Individuals who understand the nature and purpose of conceptual representations can point out areas that lack clarity or need to be further developed.

Among the important conceptual features included in the initial course map (see Fig. 1) are the following:

- We grouped factors that affect the mechanical behavior of an object into three major areas—material, geometry and loading. These areas are grouped as being internal or external to the object.
- We labeled the nature of the connections between concepts.

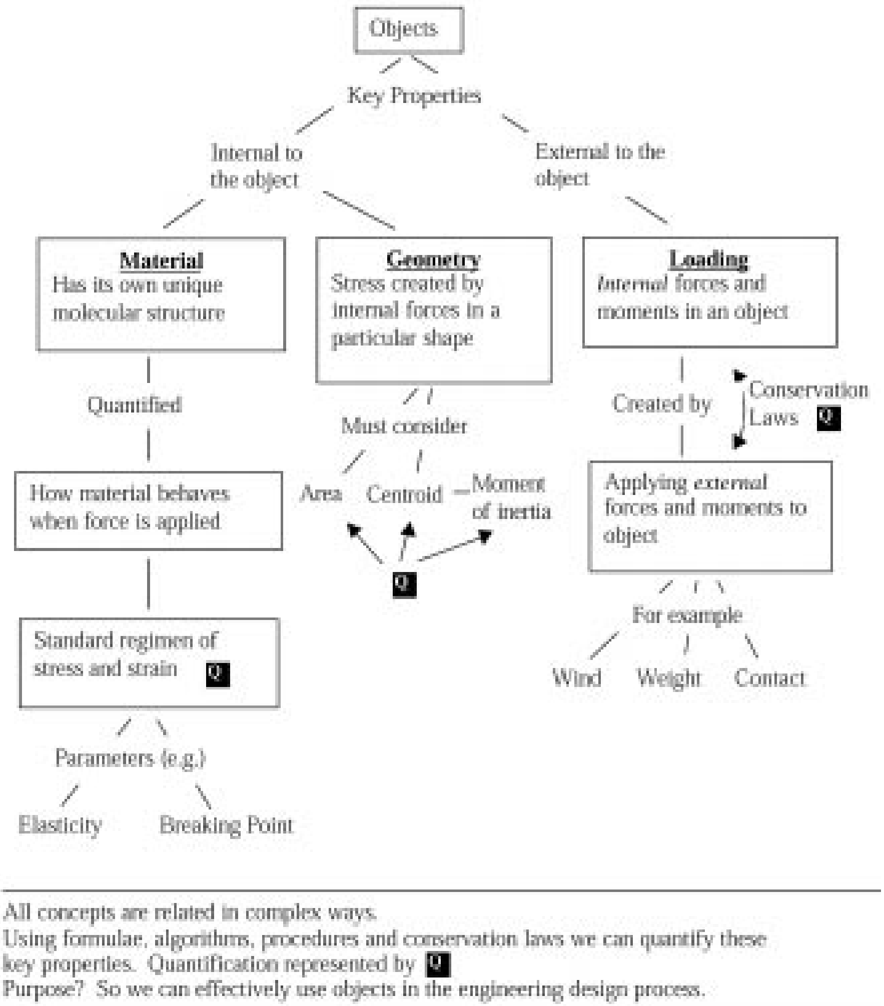

Fig. 1. Course concept map used in the beginning of EGR 270.

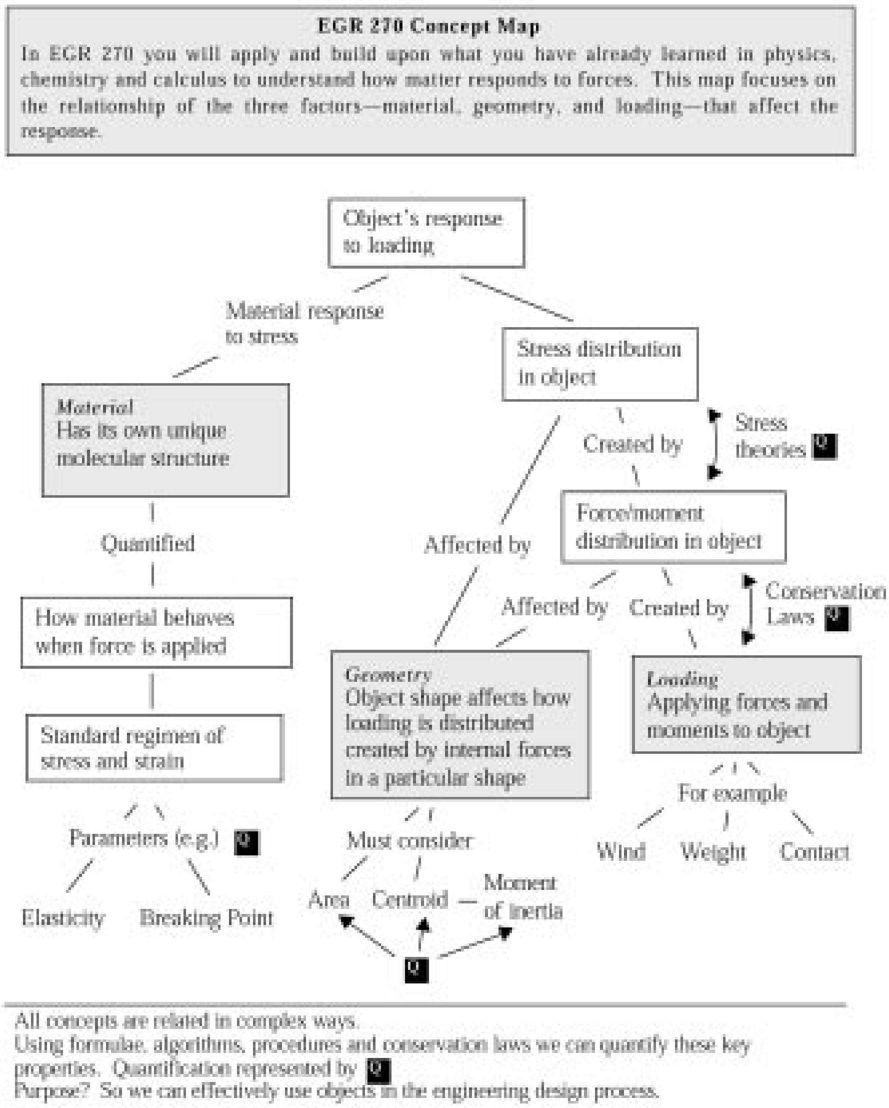

Fig. 2. Advanced course concept map used toward the end of EGR 270.

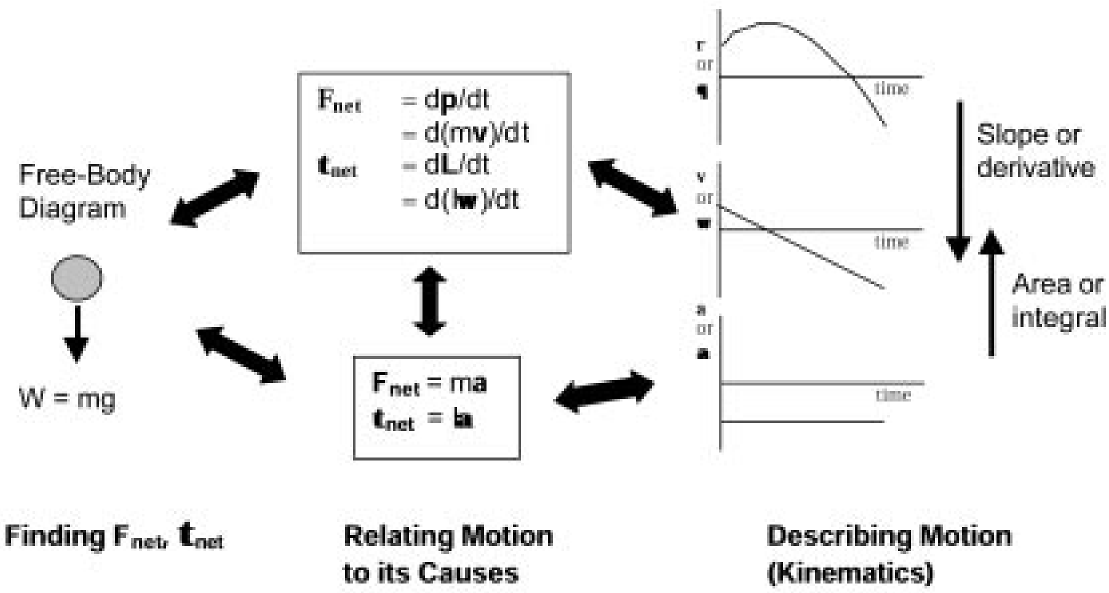

Fig. 3. Dynamics concept map used in EGR 270.

- We identified the locations on the map where concepts are quantified.

Several weeks into the course, this initial map was revised. The need for revision became apparent when students were assigned a project to analyze the structural safety and efficiency of the Washington Monument. Students needed a map that showed in more detail than Fig. 1 how loading and geometry are combined to calculate internal forces and stresses. The emphasis on grouping concepts as internal and external to the object (which was useful for introducing concepts early in the course) was replaced by an emphasis on illustrating the detail necessary for structural analysis. This detailed course map, shown in Fig. 2, more closely matches the analysis procedure of an engineer.

In addition to the course concept map, a second concept map for dynamics (see Fig. 3) was also used extensively. In this map, motion is related to its causes by Newton's second law and impulse-momentum relationships. The graphical and mathematical relationships among variables describing motion are the fundamental feature of the right side, while the left side of the map describes the forces and torques that affect the motion. On the left side we highlight the free-body diagram and its use to find the net force and torque on an object. Thus the framework illustrates the need to identify forces and torques, to construct a free-body diagram, and to add the forces and torques. In the middle of the diagram is Newton's second law and impulse-momentum relating the two sides. It has been our experience that without this representation of the entire set of relationships, students view Newton's second law and impulse-momentum as two completely different approaches that apply to entirely different situations. For example, students may feel that impulse-momentum is appropriate for collision problems and Newton's Second Law is appropriate for elevator problems. Seeing both ideas represented visually as relationships between motion and its causes shows how they fit together. A more detailed description of this map and how it is used to teach physics is given in Ellis and Turner [21].

Implementation

The use of concept maps began on the first day of class. Before seeing the map, students worked on a group activity in which they were asked to generate the variables that affect the structural safety of a bridge. This activity demonstrated both for the teacher and the students themselves that they possessed considerable knowledge of the importance of material, geometry and loading for bridge safety, and also insight into how each affected the safety of the bridge. For example, students identified that the magnitude, direction, and location of the loading are important factors. Many groups also noted more advanced concepts such as the spatial distribution and time-varying properties of the loading as affecting the bridge safety. What the students did not know was how to quantify the effect of each variable (a major course content area) and how all of the many variables were related to each other. Thus the teacher and students together identified the knowledge that the students brought to the course and how they would have to build upon that knowledge to develop mastery in the course. After completing this exercise, the class was introduced to the course concept map as the instructor essentially constructed the map by using each of the variables that the students listed. We believe that this is likely to result in increased self-efficacy since students saw that their ideas were, in fact, the basis for the course.

Throughout EGR 270 the course concept map was revisited regularly as each new topic was introduced. The purpose of using the map at these times was to help students understand why they were learning each new topic, how new concepts fit in with the other ideas already learned and where, conceptually speaking, they were headed in the future. The map was particularly useful for introducing transitions between seemingly unrelated topics. For example, many engineering statics textbooks jump back and forth between the study of geometric properties (e.g., centroids and moment of inertia) and the study of loading and equilibrium. The concept map helped students see how these topics were related and thus helped them effectively organize their new knowledge.

Because the course concept map helps student see the big picture, it is most useful when students work on big-picture activities. For example, the Washington Monument analysis project required students to synthesize all of the concepts presented in the course and apply them to a complex, real-world situation. Devising an analysis strategy and sorting through available data for relevance are two of the major challenges that students face as they begin the analysis. Because these are big-picture issues, the concept map helped bring order to what would otherwise have been an overwhelming amount of data, equations, and concepts. The instructor and students referred to the map constantly during any presentations, discussions, or extra help sessions relating to the project. Thus in addition to serving as an organizing tool, it also served as a communication tool by providing a common reference for everyone.

Another major use of the course concept map was to help students understand where assumptions and idealizations occur and their effects on other variables. For example, Fig. 2 shows that stress theories quantify the relationships used to compute stress distributions from the internal force/moment distributions and geometry. As students continue in their education, they will learn increasingly sophisticated stress theories that will result in more realistic stress calculations. Because the flow of calculations in Fig. 2 is from

Table 1. Student perceptions of achieving each of the EGR 270 learning objectives (based upon the responses of 25 of the 27 students enrolled in the course)

	Learning objective	Students who agree or strongly agree
1	I have developed a conceptual understanding of how loading, geometry, and material properties affect the mechanical behavior of a continuum.	100%
2	I have developed problem solving competence based upon fundamental principles in calculating internal and external forces for statically determinate 2D and 3D mechanical systems in static equilibrium.	96%
3	I have developed problem solving competence based upon fundamental principles in calculating internal and external forces for calculating centroids.	92%
4	I have developed problem solving competence based upon fundamental principles in calculating internal and external forces for describing the behavior of damped and forced vibrating systems.	40%
5	I have improved my understanding of calculus and physics through their application.	88%
6	I have improved my skills in oral, written and visual communication.	64%
7	I have improved my ability to work effectively in a team.	80%

bottom to top, it is clear that changing stress theories will affect the computation of an object's behavior. These theories will not, however, affect variables that are lower on the map such as the distribution of internal forces/moments or geometric properties. Nor will they affect concepts from the material strand.

The more focused dynamics map (see Fig. 3) was first used as an organizing tool for a review of Newtonian mechanics and then later as an aid for solving rigid body dynamics problems. To solve problems, the students used the map to locate the variables that were given in the problem statement and that needed to be calculated. The pathway between the variables was then identified as the solution procedure. For example, if the forces on a tire with a fixed axis were given and the angular displacement needed to be found, the solution path would be to (1) draw a free-body diagram to calculate $\tau_{\mathbf{net}}$, (2) relate $\tau_{\mathbf{net}}$ to α using $\tau_{\mathbf{net}} = \mathrm{I}\alpha$, (3) integrate α to find ω, and (4) integrate ω to find θ. They could also choose an alternative solution procedure by using the impulse-momentum path relating $\tau_{\mathbf{net}}$ directly to ω. In fact seeing that either path could be used for solving problems surprised many students who entered the course not understanding the relationship between Newton's Second Law and impulse-momentum. Although

Table 2. Student perceptions on the helpfulness of conceptual frameworks used in EGR 270 (based upon the responses of 19 of the 27 students enrolled in the course)

	How helpful is it?	
Student	Course concept map	Dynamics concept map
1	shows direction of course which is good	Extremely helpful! Helps show how all those formulas and concepts are related which helps me to understand new ones based on old ones I'm already confortable with
2	extremely	Extremely
3	confusing	
4	very helpful	Very helpful
5	a good reference to keep in mind as the course goes on. Puts things into perspective	Puts the class and semester into an easy to understand form. We always know where we're going
6	It was very helpful in outlining EGR education	Helped to synthesize imformation
7	nice! Definitely helped to see the big picture	Really great? One method of looking at all that type of problem
8	helpful but not sure how book follows map. Maybe add chapters to map	Helpful but I wish I had a review of integrals first
9	I like maps	What is this?
10	It was okay. I don't know if the map is really that important.	I think it's really important
11	it is interesting, especially to keep the big picture in mind	Extremely helpful
12	Helpful	Very helpful
13	very helpful to see the big picture	Very to see how everything fits together
14	most classes just dive right in, but this actually tells you why you're doing what you're doing—very helpful	Very! It's great to be able to fall back on the basic F=ma when I'm struggling with a problem. The graphs are very helpful also
15	it's nice to visually see how this course fits into the big picture	This was very helpful for me to understand how to set up every problem. I think it's a very good approach for this class
16	it's good to have a sense of what this class is about at the beginning of the semester	Very helpful in clarifying the concepts
17	pretty helpful in understanding the big picture	
18	they were fine, but not very useful	Good reference
19	seems necessary	Necessary

students had never seen the map in a physics course, they still chose to use it extensively. When presenting solutions in class, solving homework problems or asking questions in class, the map was constantly referred to by the instructor and student. Because of the complexity of applying theory to real-world projects, the map proved to be particularly useful in a project requiring students to videotape and analyze the motion of their own bodies.

Evaluation

All 27 students in EGR 270 were asked to complete a pre- and post-course attitude survey, a mid-semester survey on the effectiveness of the instructional strategies used in the course, and a post-course survey on achievement of course goals. Student focus groups covering all aspects of the course were also convened at the end of the course. All of the evidence indicated that most of the students had a positive experience in the course. Students generally perceived that the educational objectives for the course were met (see Table 1). Student confidence increased dramatically. At the beginning of the semester only 11% of the students in the class agreed or strongly agreed with the statement, 'I feel confident in my skills, abilities, and knowledge in engineering.' At the end of the course, 81% agreed or strongly agreed. The number of students who agreed or strongly agreed with the statement, 'I am committed to a career in engineering' rose from 56% to 69%.

Students perceived Objectives 1, 2, 3 and 5 to be the most effectively achieved. These were also the objectives in which concept maps played the largest role. But how much of the success in meeting these objectives was due to the use of conceptual frameworks? In a mid-semester survey students were asked to rate the effectiveness of a variety of instructional strategies used in the course. Their responses for the course concept map and the dynamics concept map are shown in Table 2. The majority of students found both maps to be helpful. The course concept map and narrative were often mentioned as helpful for seeing the 'big picture.' Their helpfulness for showing direction, providing perspective, telling why you are doing things, and providing a sense of what the class is about from the beginning were also mentioned. Only two students expressed a negative opinion—one thought that they were confusing and the other did not think that they were useful. Student response to the dynamics concept map was more effusive as students used terms such as 'extremely' and 'very helpful' more often than for the course concept map. The dynamics framework was cited as being useful for showing the relationships among formulas and concepts, synthesizing information, clarifying concepts, and setting up problems. Several students noted that by illustrating the similarities between how the linear and rotational motion knowledge is structured, they were able to more easily transfer their understanding of linear motion to the more advanced topics of rotational and combined motion.

Another measure of the usefulness of concept maps for seeing the big picture of the course is a comparison of post-course student questionnaires. In the year that concept maps were used 92% of students agreed or strongly agreed with the statement 'the course goals and objectives were clear,' whereas only 60% of the students in the previous year's class (same instructor) held that opinion.

At the end of the course two focus group meetings were held, consisting of 5 and 7 students and led by a moderator unconnected to EGR 270. Although the focus groups discussed many aspects of the course, they were specifically asked to comment on the course concept map. Typical comments on its use were:

> Yeah, he used that a lot. . .When we would go to different topics, like we'd start a new unit . . . he would just relate back to it . . . and see where we're going in the math, and things could be related to when we get to fluids and materials. . .it was helpful.
>
> I think the concept map is . . . in your head, where you just suddenly click: oh, everything is linked!
>
> It was nice to see that what you were doing was actually . . . something to be used later on that you would need, not just doing something with no end, no goal . . .
>
> . . . the fact that he keeps on bringing it back in—after a while you're like. . .I'll listen to what you're talking about. And it is helpful. . . I think now, at the end of the course, it definitely makes perfect sense to have that.

One student compared her experience in EGR 270 to a course in materials that she had taken at a university. She describes the university course as:

> It's on materials. . .and all the professor does is tell us how to read a graph and then derive equations, and you derive equations for an hour every day, and he doesn't ever tell us what they're for. . .

And then compares it to EGR 270:

> And in this course [EGR 270], you always know what you're doing, and he makes a point at every new chapter to go through the concept map and [says] 'so we learned how to do this, which means we can now do this, which relates to this, and it makes everything make sense.' So you're able to say, 'Even if I don't understand the math, this is what it's for.'

One common concern raised by a number of students in the focus groups was that it was intimidating to start the course with the map. One said,

> At the beginning of the course I was nervous about the concept map, because half the words I didn't even understand, so I knew that it wasn't until this point [the end of the course] that I would actually get it.

Another student commented,

> It has to be introduced at the beginning. You have to know what all these things are that this course is [going to] cover; whether or not it's overwhelming is irrelevant, because you do cover all of that. But there is no way to introduce it in which I wouldn't

Table 3. Guidelines for Using Concept MapsDevelop initial map(s)

1. Develop initial map(s)
Decide on the scope of the concept map(s) needed. These can be course level or program level maps that include all the major ideas and their relationships, and/or they can be more focused maps depicting, for example, problem solving strategies, unit or chapter ideas, or student's prior knowledge.

2. Introduce maps to students
Introduce maps after an initial activity in which students identify and articulate related existing knowledge.

3. Use maps
Refer to maps whenever new ideas are introduced to point out how the new ideas are related to ideas already learned by students. Refer to maps whenever course material is reviewed in order to make explicit and emphasize the ways the reviewed material relates to the overall course structure. Refer to maps when analyzing phenomenon of interest to show how the ideas provide a 'template' or frame of reference for thinking about the phenomenon. When teaching or reviewing problems and their solutions, refer to maps in order to focus on and include strategic knowledge in classroom discourse. Show how the maps can be a useful engineering tool by using them regularly in analysis and design applications.

4. Revise maps
Initial maps are necessarily approximations. By engaging students with the beginning maps, they become familiar with the concept map as a tool for thought and they become participants in reshaping and refining the map to better serve their growing understanding. Refinement often adds detail, but can also result in a 'master' map that is lean and shows the major relationships among ideas.

5. Repeat steps 3 & 4

immediately discount it and then later on realize that it was important.'

DISCUSSION

Based upon our experiences, Table 3 presents guidelines for the use of concept maps in the classroom. Although the intention of using concept maps was to emphasize the big picture to the students, their use affected the instructor also. Constructing the maps required extensive reflection to identify and organize the major topics in a way that facilitated student learning. In addition to thinking carefully about the organization of the information in the course, the instructor also had to consider the knowledge and experiences that the students bring to the class and the process for them to acquire the knowledge presented in the concept maps. During the process of developing and refining the maps, the collaboration of the instructor, colleague and student brought new approaches into the course. For example, beginning the course by first grouping properties as being internal or external to the object and identifying areas of quantification on the course map were a result of this team process.

One way that using concept maps helped students see the big picture was by providing them with a tool that supported learning through real-world projects. Because of the time involved in completing these projects, it became clear during the course that there was a need for new classroom examples, homework questions and assessment tools that focused on the big picture concepts without time-consuming calculations. Thus questions were developed that required students to identify and understand key concepts in real-world situations, but not perform calculations. For example, in one homework question students were asked to investigate the safety of the design for a business sign to be hung above a busy sidewalk by describing the important concepts that needed to be considered.

SUMMARY AND FUTURE WORK

Pedagogy that highlights and emphasizes the conceptual inter-relatedness of content and topics seems essential if learning in engineering courses is going to be meaningful. Not only new ideas, but also the existing ideas that students bring to instruction need to be included in this explicit treatment. Having a framework (or frameworks) to support thinking about course content as well as a way to think about solving problems has proven beneficial to students. We believe that concept maps are an excellent tool for achieving these outcomes. This is particularly true when the maps change to keep pace with student learning.

We recognize that a rigorous process aimed at producing evidence bearing on the effectiveness of concept maps used in this way is very important and we intend to pursue the research that will be needed to do this. An essential study will be to track students through subsequent courses to see if they continue to make use of concept maps especially when not prompted to do so by the instructor. A study comparing students taught using maps with those in 'mapless' instructional settings as they represent and solve problems will also provide important evidence bearing on the effects of concept maps. Our anecdotal evidence as well as that generated by student feedback suggests that this is a promising pedagogical and learning tool in engineering education; one worth examining more closely.

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