Instructor-Developed Course Concept Maps Used to Contextualize Material

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Abstract

During a semester, students often focus on the individual class lectures and topics, failing to see the global picture of the course material. However, with the aid of a concept map provided by the instructors on the first day of classes, and referred to throughout the semester, students may improve their "big picture" understanding of the course. For example, in the Ship Structures course taught at the U.S. Coast Guard Academy, nearly half of the lectures are devoted to designing against the failure mode of yield (19 lectures), while the modes of buckling, and fatigue and fracture have only a few lectures (3 and 2 lectures, respectively). Students previously misunderstood that yield was "more important" and did not recognize that there are other failure modes that must be checked for in design. An instructor-developed concept map was used to help students see that, despite the large number of lectures required to fully understand yield as a mode of failure, it was equally important as the other failure modes. This paper outlines the development and implementation of three concept maps: Dynamics, Fluid Mechanics, and Ship Structures.

Keywords

Concept Map, Mind Map, Dynamics, Fluid Mechanics, Ship Structures.

Inspiration

After teaching several courses (Dynamics, Fluid Mechanics, and Ship Structures (co-taught)) all for a second time, the author recognized that many students couldn't classify the topics they had learned. The knowledge was too compartmentalized, and the global topics eluded the students. This was as expected since this was the first time the students had been exposed to this material. However, when the final exams of all three courses require combining information in a comprehensive exam, the inability to understand what topics to consider was proving problematic. All three courses are also prerequisites to other courses in the engineering curriculum. In an attempt to have students learn the "big picture" coincidentally with the lecture topics, the author referenced what had already been implemented in the U.S. Coast Guard Academy course Mechanics of Materials: a concept map[2,3].

Concept maps were introduced into science and engineering by Novak and his research group at Cornell in the 1970s[9]. Fang[5] succinctly defined concept mapping as a "graphical representation" showing "how individual concepts are related to and connected with one another to form large wholes". Concept mapping has been used as a way to "organize and represent knowledge"[10].

Students often miss the overall concept of a course when focusing so much on each individual lecture and problem. A concept map helps with the "big picture" of the course[2,4]. Ellis et al.[4] went on to describe student learning as follows:

> "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 learning in useful ways."

The concept map can then serve as a "scaffold" to learning[10]. This aids in the learning process since many engineering courses take a "bottom-up" approach to the material, with increasing difficulty, so without that "scaffold" students do not recognize how to connect the "incremental bits and pieces" of the material they are learning to the bigger picture[4].

Anecdotally, one student was willing to admit after the Ship Structures final exam that they thought they only had to check for failure due to yielding and not buckling or fatigue and fracture. When further probed, it was recognized that with so much of the course devoted to the failure mechanism of yield (19 lectures) versus the a total of 5 devoted to the other failure modes, students were missing the larger picture and presuming length of time to properly cover a topic was directly proportional to the importance of the topic in comparison to the rest of the course. Many other students shared this one student's perspective on the skewedness of the lecture topics.

In Dynamics, many students failed to recognize that there were three techniques being taught in Kinetics (Newton's Second Law, Work and Energy, and Momentum) that could all be useful in solving a problem, and often any one could be used to get to the same results. Each topic was viewed as separate by the students, and the overall interchangeability of topics was lost in the learning process. Likewise, in Fluid Mechanics, differential versus integral approaches, although both taught, were not viewed as parallel approaches to conservation of mass or momentum. Despite the use of the terms "Conservation of Mass" and "Conservation of Momentum" in the text and lectures, students failed to see the analogy.

It was decided to use an instructor-developed concept map over student developed after reviewing several statements as to the ability of students to develop a meaningful map during first exposure to material. Egelhoff et al.[3] and Egelhoff and Burns[2] found that student-created maps were riddled with misconceptions, missing core topics, and missing linkages. Students would also see the topics as "disjointed and unrelated"[3]. The linkages, therefore, needed to be drawn for the students. Egelhoff and Burns[2] hypothesized that a "common" concept map provided by the instructors would be effective at teaching and reviewing topics for the course of interest. Ellis et al.[4] reiterated that an expert (instructor) making a concept map for students makes the experts understanding of the material more evident and helps the students to better understand the structure of the knowledge as such. Along with providing a "big picture" and structure for the course, a concept map can aid in dispelling misconceptions that students have going into a course. With the linkages already explicit in a concept map, the knowledge structure is withheld and misconceptions dispelled[4].

Table 1: Dynamics course topics in order of presentation, with number of lectures devoted to each topic.

Topic	No. Lecture Hours
Particle Kinematics	6
Particle Kinetic	8
Rigid Body Kinematics	6
Rigid Body Kinetics	10
Vibrations	7

Table 2: Fluid Mechanics course topics, not in order of presentation, with number of lectures devoted to each topic.

Topic	No. Lecture Hours
Fluid Characteristics	5
Statics	4
Conservation of Mass	1.5
Conservation of Momentum	7.5
Conservation of Energy	16

Table 3: Ship Structures course topics in order of presentation, with number of lectures devoted to each topic.

Topic	No. Lecture Hours
Geometric Properties	3
Loading	2
Yielding	19
Buckling	3
Fatigue & Fracture	2

Development

Each concept map was developed using the course description, outcomes, schedule, and textbooks. It was decided that for each concept or equation, an image would be used alongside. Images are "powerful memory enhancers for most engineering students"[3].

Dynamics was by far the most approached course for a concept map by other institutions. Fang[5] introduced a "Tree of Dynamics" to encourage students to look for the linkages between topics of this challenging course. Fang[5] correctly stated that Dynamics is often found to be one of the most challenging courses in undergraduate engineering with its numerous fundamental concepts. This leads to students failing to know what concepts to apply and when[5].

The author first used the schedule of lectures (summarized in Table 1) to develop a draft of the Dynamics concept map. She then shared this with the other instructors of the course. Another instructor already showed his students a Dynamics "grid", showing the flow of the course with arrows from particle kinematics to particle kinetics, then back to kinematics of rigid bodies

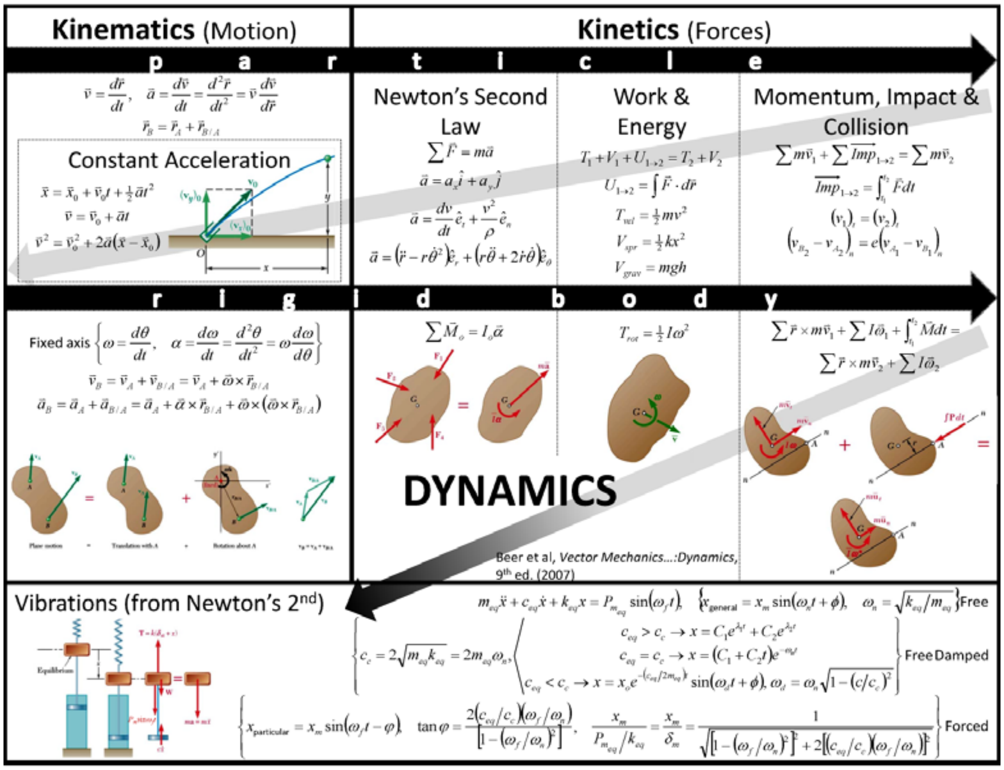

Figure 1: Instructor-developed Dynamics "Concept Map" derived from course topics (many figures borrowed from Beer et al.[1]).

before continuing on with kinetics of rigid bodies, and concluding vibrations. The draft concept map was then overlaid on this grid to unify these concepts and provide the concept map with more structure. The result is shown in Figure 1.

In Fluid Mechanics, some subjects incorporate multiple topics, and some topics were introduced in multiple formats (e.g. integral and differential forms of the Conservation laws). The topics listed in Table 2, then, are often revisited, particularly conservation of energy, which is started with Bernoulli's Equation, and then finished when pipe losses have been covered towards the end of the semester. The resulting Conservation of Energy equation is often referred to as "Super Bernoulli" by the author to convey this connection to the root equation. The most complete form of the equations is used for simplicity, as seen in Figure 2.

Ship Structures was definitely the most interesting to approach, as some topics would occupy such a small percentage of the overall lecture content, such as two days towards the end of the semester being devoted to fatigue and fracture, yet the importance of this topic as a failure mechanism is no less than the 19-lecture topic of yield (summarized in Table 3). The resulting concept map (Figure 3) was significant to the author as it allowed her to become the expert in a

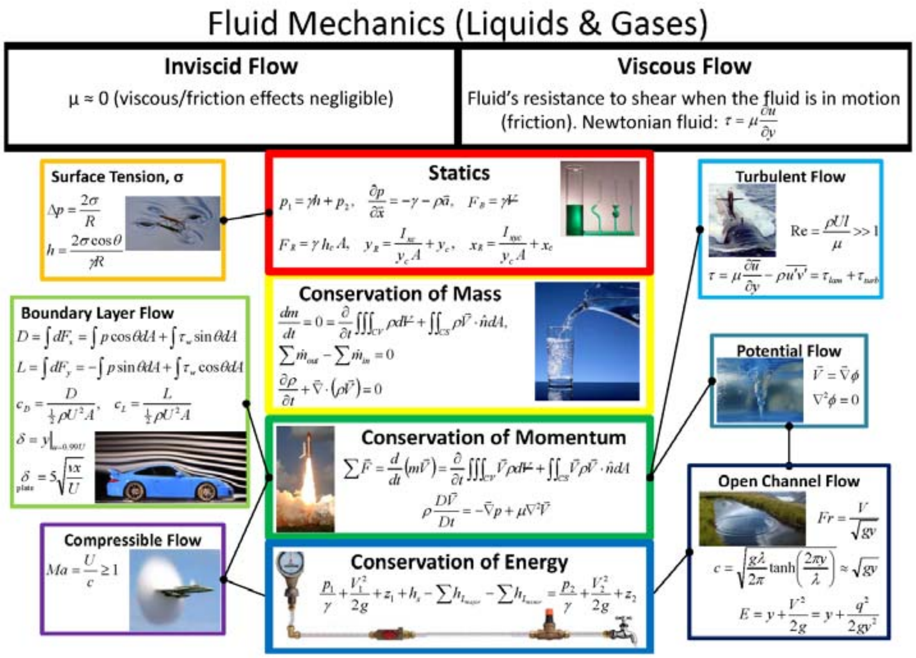

Figure 2: Instructor-developed Fluid Mechanics "Concept Map" derived from course topics.

field that was tangential to her field of expertise and had only co-taught the course, conveying knowledge to the learners as described by Ellis et al.[4].

Although textbooks are used in particular for the concept maps for Dynamics and Ship Structures, the required text for each course could change but the concept map would remain unchanged. It transcends the textbook. Additionally, each equation or figure need not be complete as they are supposed to trigger the use of the actual equation or table or whatever resource is being referenced[2].

Implementation

Each concept map was printed out in large format and placed into a poster frame, hung inside the classroom. Additionally, it was included in the hardcopy and electronic copies of the syllabus and course schedule. As recommended by McKeachie and Svinicki[8], the concept map is introduced on the first day of class, giving students an overview to the subject matter, although this is an instructor-developed concept map rather than a student developed map.

The concept map is referred to throughout the semester. It is particularly useful when reviewing for exams as well as when a new concept is being introduced. It helps to contextualize the course material and track progress through the course.

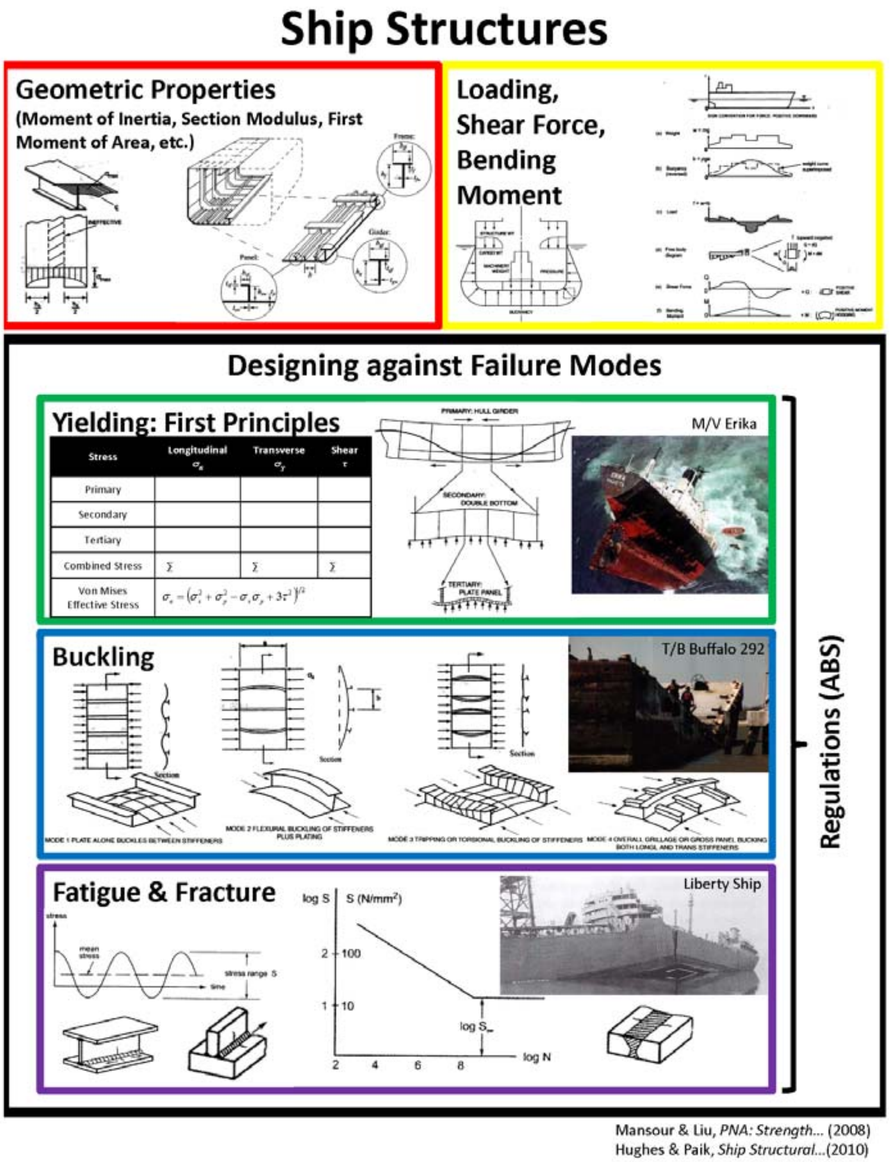

Figure 3: Instructor-developed Ship Structures "Concept Map" derived from course topics (many figures borrowed from Hughes and Paik[6]; Mansour and Liu[7]).

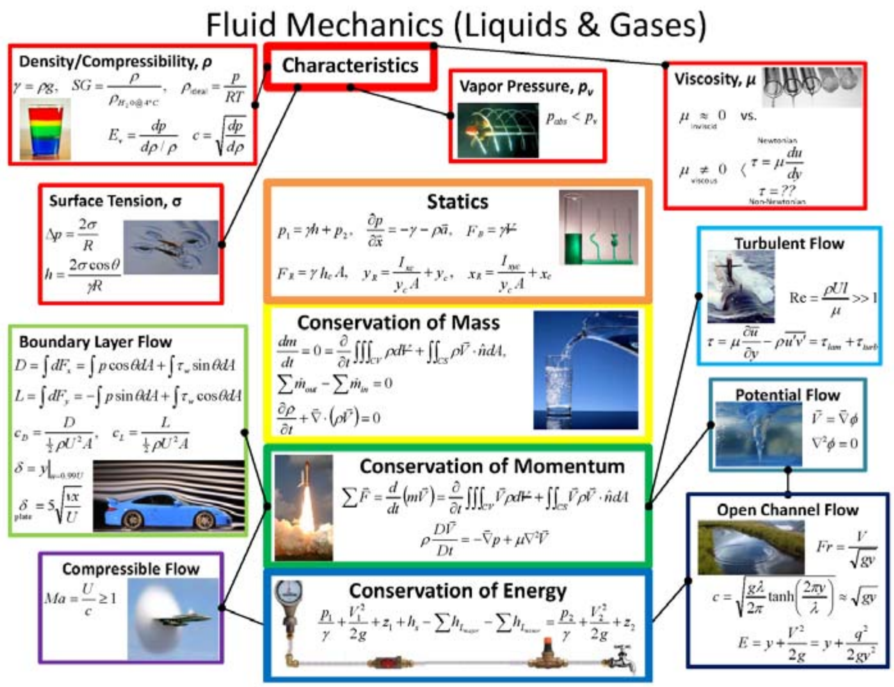

Figure 4: Revised instructor-developed Fluid Mechanics "Concept Map" derived from course topics with continuous improvement efforts.

In addition to helping to place the course in context, it has also helped to create more clear breakpoints for the courses. In particular, in the Dynamics course, there were previously three or four exams throughout the semester, with odd break points in the middle of particle and/or rigid body kinematics. However, having a clear concept map for the course with 5 specific sections, a five-exam format was implemented successfully into the course.

The first semester the concept map was used in Fluid Mechanics, students had the opportunity to make their own concept maps even after viewing the instructor-provided map. There were very interesting results, such as a game board format, but none showed the understanding of interrelationships shown on instructor-developed map, and there wer often omissions or misconceptions present, just as found by Egelhoff et al.[3] and Egelhoff and Burns[2] and Fang[5].

There does appear to be an issue where students may be able to read the concept map on the first day, but they are not able to understand it until the material has been fully presented at the end of the course. This was found to be true by Egelhoff and Burns[2] as well, where Electrical Engineering students who had never seen the concept map before were confused when using it for a general Fundamentals of Engineering review, whereas students in other majors that had seen the concept map before found it very useful. It appears that a one-page course summary in the form of a concept map, despite the simplicity, does not become an effective tool until the concepts have been introduced throughout the semester.

However, referring often to the posters of the concept maps in the classroom did allow students to see how far through the course they were progressing, and mentally noting as they went along how much of the concept map now became significant and meaningful to them. The posters were also left visible during the final exams to serve as a "cheat sheet" for those that recognized the value.

Conclusion

Each concept map is considered a work in progress; there is always room for continuous improvement. The development of each concept map is an iterative process[4]. Just the reflection provided by writing this paper allowed for some further inspirations for the Fluid Mechanics map, particularly in the Inviscid vs. Viscous Flow, broadening this to the subject area of Fluid Characteristics as shown in Figure 4.

The concept maps have now been in use for three iterations of each course, and have become an integral part of the class. Fewer students have questions about how each concept fits into the big picture of the course, and students no longer express tunnel vision when trying to understand the importance of one topic over another or the interrelatedness of topics.

Disclaimer

Elizabeth MH Garcia is a professor of Naval Architecture and Marine Engineering at the U.S. Coast Guard Academy. The views here are her own and not those of the Coast Guard Academy or other branches of the U.S. government.

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