Use of Concept Maps to Build Student Understanding and Connections Among Course Topics

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Abstract

Students often have a difficult time becoming strong engineering students because they are used to some of the prerequisite courses in science and mathematics being somewhat formulaic and "plug-and-chug" in their approaches. When students have been challenged by prior courses that are not formulaic, they often rate them as being harder or complicated. The transition of becoming more broad-thinking in problem approaches is a difficult one, even for very hard working and bright students. Concept maps enable instructors and students to more concretely describe connections among different course topics and to place new knowledge into a comprehensive problem solving framework.

Examples of concepts maps from a series of chemical engineering courses are used to discuss how the idea of concept maps can be used in different ways. Concept maps built over the semester for a sophomore material and energy balances course are used to highlight how layering of new concepts and an inherent increase in complexity leads to a comprehensive overview of material. Use of the concept map in lecture example problems demonstrates how one can utilize the given problem statement to see how solutions to conceptually challenging problems are built. A concept map from an equilibrium thermodynamics course at the junior level is used to show how disparate yet interrelated ideas can be bridged together through a hierarchical definitional approach. Finally, a concept map illustrating sustainability in the context of technical, social, economic, and environmental issues for a senior design series is examined for pedagogical relationships on why certain topics were selected for the courses.

Student feedback has consistently shown that the idea of concept maps enables students to solve more complex problems with greater confidence. Students have also indicated that they have developed concept maps for subsequent courses on their own, even though it was not required and instructors did not encourage these efforts. Students seem to benefit from these activities.

Introduction

Faculty in engineering often suspect that prerequisite courses in science and mathematics are focused on formulaic approaches to solving problems. This is sometimes called the "plug and chug" method where students may not understand the fundamental concepts but will superficially link mismatched concepts together, leading to poor performance in the prerequisites and a weak foundation for building the core engineering topics. Sket and Glazar observed high school chemistry students who did not organize their knowledge, knowing the individual reactions, but not how to link a series of reactions together[1]. Students in the prerequisite science courses, then, may be attempting to learn more superficially than what will be required of them later on. This view of teaching and learning fits well with an investigation of how some faculty see teaching as transmitting information and students learning as receiving this information[2], without much focus on how the information really functions. The work by Hendersen, et al., used a focal problem from physics to investigate faculty perceptions of teaching and learning problem solving where the problem would require an average student to use exploratory decision making as opposed to an algorithmic or "plug and chug" approach. A significant number of faculty viewed their role as a knowledge transmitter and not a problem solving enabler.

Much of the material in prerequisite courses prior to the beginning of core engineering courses is oriented towards factual recall. It is on these foundations that the engineering problem solving skills will be built. Ausubel's theory of assimilation[3] points out that linking to prior knowledge is a key to building long lasting and useful skills. In essence, knowledge must be organized in order to be accessible from long-term memory[4]. Students who possess isolated information about concepts on a factual basis will remain novices and be unable to solve complex problems.

Students often have difficulty transitioning from fact recall courses to more integrated and informationally cross-connected courses in engineering. This may be because students have yet to learn how to create a scaffold for holding new information in a coherent whole where topics are related to each other. Concept maps may be one way of enabling students to succeed in overcoming this difficult transition to problem solving and critical thinking.

Concept maps and their history

A recent meta-analysis of concept and knowledge maps points out that diagrams like these originated as far back as the 13th century[5]. However, their use has seemed to explode recently with a much larger number of publications appearing in the literature. Even just since 1997, there have been 500 peer-reviewed articles that have investigated their use, according to a brief survey of Journal Citation Index.

Novak[6] proposed the concept map as a way of created a knowledge network that contains points and verticies as concepts and links between them as the relationships among concepts. Kinchin and Cabot point out that there have now been 25 years of extended research and development of using concept maps to help students learn how to learn[7]. Essentially, concept maps are two-dimensional representations of a set of concepts and their relationships[8]. Being graphical in nature, they show the conceptual, relational, and hierarchical nature[9] of topics in a course or series of courses.

How instructors use concept maps

Concept maps have a rich history of application in the medical education literature[8-10] For instance, concept maps have been used to evaluate student learning of CD-ROM based educational materials in MRI imagining[10]. Hay, et al., showed that concept maps could be used, even in small classes of only six medical students, to investigate how deeply and richly students perceived new topics after a short-term assignment requiring use and assimilation of a 6-8 hour long electronic teaching tool that covered both case studies and more rote learning through a tutorial. Students drew a map of their pre-knowledge of MRI technologies and then drew a second one after exposure to the material. Students were evaluated on the structural changes in the hierarchy of organizing concepts, their use of expert terms, and then through a blind-evaluation of the pre- and post-mapping exercises. Of the 78 concepts detailed by instructors, only 28 showed up on any of the student maps, and at that, only half of the module sections were represented. It was noted that preknowledge of the material or prior experiences were a very strong determinant of the final concept map structure. The authors ended with a suggestion that the concept maps may have wide-ranging utility that may help some students more than others, particularly noting that concepts maps were a visual representation of linkages between material.

Diwakar, et al., used concept maps extensively to teach physiology to veterinary students[11]. Their work was motivated by the fact that concept maps provide a visual road map showing how students may connect meanings of concepts together. The authors expended effort developing assessment tools for evaluating student-constructed concept maps. A preliminary study of their method was done with freshman students who were graded on maps they had drawn. Forty-eight percent of the students reported liking the concept maps, but 28% did not like them. The authors went on to use concept maps extensively as a student assessment tool in a first-year veterinary medical school course on physiology. The course consisted of two exams, seven quizzes, and 11 concept-mapping assignment in addition to five laboratory reports. The concept mapping exercises constituted 17.5% of the total grade in the course. Students were surveyed about their likes and dislikes of the concept maps and only 21 % reported liking concept maps, but 81 % felt that concept maps helped them understand material and 68 % thought it helped them organize information. So, while students don't like them, they self assess themselves to benefit from them, indicating there may be some resistance to using concept maps as an assessment tool. Students reported spending about 3 hours in developing a satisfactory concept map and that it took them an average of 3.3 attempts to create one they liked.

Kaya discusses using concept maps to evaluate the changes in the conceptual understanding of 47 prospective science teachers in a general chemistry laboratory class[8]. Their goal was to develop assessment tools that would prove the acquisition of higher-order thinking processes instead of just factual recall and basic skills. The structure of the course was a 15 week long semester with 3 hour labs. Students spent one semester prior to the one with this course learning how to develop and use concept maps and then they were evaluated on their concept maps in the course. Students were asked to individually prepare concept maps prior to the laboratory exercises and then they performed peer evaluations of each other's maps. After completing an experiment, students again did their own maps and then peer evaluated each other. Expert evaluation of the pre- and post-lab concept maps allowed for an examination of how deeply students were learning the material, and the author found that for almost all topics, students developed concept maps that were more interconnected and complete after the experiments. Quantification was difficult to score and the process of evaluation was very cumbersome in that work.

Moni, et al., worked with second year dentistry students to explicitly teach concept maps to facilitate meaningful learning for a four week long segment of the course on cardiovascular, respiratory, and renal systems. Concept mapping exercises and scores contributed to six percent of the students' final grades. During the four weeks, students participated in a 50 minute long introductory workshop on concept maps on other topics. Students were then given a case study where they worked in a team for 1 week to make a concept map detailing the interrelationships between different concepts and the case study. The 1 week time period included a 2 hour workshop where students discussed their work with the faculty members. Two faculty members then evaluated the concept maps with a complex quantitative scoring system, discussed differences in their scoring, and then led mediated discussions with the students to arrived at the final grades. Finally, students were given a survey about their experiences and 42 % of the students felt that concept maps help put everything together linking multiple concepts, but 40 % thought the exercise was too time consuming but worth the effort. In a follow up work, the authors used their newly designed assessment rubric and investigated student opinions of the tool more[12]. They found the concept mapping activities were not favored by students but that their like/dislike of the tool correlated with their grade.

Schau and Mattern discuss additional uses for concept maps other than in assessment[4]. They point out that instructors can use them in instructional planning, which will be discussed later on in this work, and as learning tools. Concept maps are effective learning tools both when given to students and when created by students. As discussed before, creating concept maps forces students to attempt to organize information. However, having concept maps provided allows the students to see a hierarchy or overall structure to which they can anchor new concepts within the framework of their own understanding. Schau and Mattern also discussed some quick and efficient methods of using concept maps that have not been discussed in the other works, which is to use them as a template where varying degrees of node identifiers or links have had their labels removed and students must fill in the missing information. This can be done either without providing them with the missing information or by also giving them the list of information to be added. These instruments are extremely easy to evaluate compared to the previously described assessment tools.

Kinchin and Hay showed one could use preliminary concept maps to aid postgraduate trainee teachers learn aspects of biology[13]. They used the preliminary maps to build teams of students who then worked collaboratively to flesh out more complete maps that detailed the topics. The students received 2 hours of concept map training followed by developing individual maps and then creating a group one. The authors described three types of concept maps to elucidate how to build the teams, spokes which were very straightforward, chains, which only had linear connections among ideas, and nets, which had more node connections among different levels. These net diagrams can be used to employ technical terminology to enhance meaning, in their view, and it is nets that will be used later in this work. They pointed out that concept mapping tools for learning are often underutilized, but do not discuss, much as others have, how one can actually use concept maps to enhance deeper problem solving skills instead of just in building a fact/knowledge diagram.

Pre- and post- exposure to material concept maps were used by 32 freshman students in evaluating self-awareness of limitations of missing knowledge of computer hardware[14]. Students drew one concept map on their own regarding the material using a somewhat constrained computer-based tool before comparing their maps to those of their peers. Students then redrew their own maps. Pre- and post-maps were evaluated by three experts who were trained with the same computer-tool and with the same terminology. Unfortunately, only 25% of the students thought the mapping procedure helped them find conceptual faults.

Kinchin and Cabot point out that there has been a shift towards PowerPoint based lecture materials in many disciplines[7]. Unfortunately, much of the information presented in the

PowerPoint format is organized in bullets that are sequential in nature, often burying connections among topics in the details of the sequences. However, concept mapping promotes integrated knowledge structures using multiple perspectives that are focused on meaningful learning. In their short work, the authors used PowerPoint-based concept maps to supplement learning for 37 third year undergraduate dental students in a section of a course dealing with the problem solving aspects of developing a partial denture design. Students were given two separate PowerPoint slides, one that was a traditional bulleted format of the information and another that was a concept map showing relationships between content. Ninety-two percent of students reported that the slides in the bullet-point format helped in memorization while only 43% said this of the concept map format. However, 95% of students felt the concept map helped show connections between individual concepts. Unfortunately, there was no evaluation of whether student perceptions carried forward to improved performance.

Another paper pointed out that instructors could use concept maps to help students better tailor their instructional approaches in e-learning environments[15]. The paper then went on to develop fuzzy logic analyses to automatically generate concept maps for courses using student performance on exams as a guide. The generalizability of this approach may not be feasible for open-ended engineering format questions and material.

Creating access to prior knowledge and activating students to be receptive to new linkages was explored by Gurlitt and Renkl with 43 high school and 45 university students using physics as the subject matter[16]. The premise is that students primed to access prior knowledge would be more involved in developing deeper linkages among concepts on a particular topic. The experiment was very short in duration, approximately 1 hour and 15 minutes, where students were exposed to the idea of concept mapping, given a partially constructed expert map, and asked to fill in additional information. After that, students were given access to web-based textual materials that explored different topics. Students then took a post-test of the material and contained both open ended and multiple choice questions. While there were many inconclusive results, the authors found that there was enhanced learning after use of the concept map to activate areas of prior knowledge and prerequisite material.

Development of concept maps was linked with learning styles in a study of 120 nursing students[17]. Again, the main theme in nursing like in engineering education, is to develop critical thinking skills in students which includes interpretation, analysis, evaluation, and inference with the ability to provide the rationale for one's judgment. Concept mapping was proposed to be a method of evaluating meaningful learning on the basis of Ausubel's[3] assimilation theory. In the study, students were invited to participate, which may have led to some self selection effects. Data collection was brief, with two 10 minute assignments during the semester, one to complete a learning styles survey instrument and one to complete a concept map. Concept maps were then evaluated by faculty members using an internally consistent peer comparison ranking process, which may have had some subjectivity. The learning styles groupings did not include a visual-verbal category so it is interesting to consider whether the inclusion of this type of axis from Felder's work[18-21] would have led to stronger correlations. In the nursing work[17], abstract learners were twice as likely to have preferred using concept maps over more traditional case study materials. The authors ended with the idea that concept maps may be more effectively used as teaching tools than as grading or evaluation assignments.

Only one paper in the literature surveyed by the author discussed using concept maps as a teaching tool as suggested in the previous paragraph, and that was the work of Sket and Glazar[1]. The authors lay out a hierarchical detailing of organic chemistry syntheses reactions using oxidation/reduction mechanisms as one axis and individual reactions along the other axis. The authors then show one example of how one could use their concept map to answer a fill in a homework exercise, leading the reader through how to use the concept map. They give a few other simple examples that would rudimentarily benefit from the concept map. They end with the thought that elaborated concept maps enable students to integrate concepts successfully.

A meta-analysis published in 2006 examined 55 studies involving 5818 participants ranging from elementary school age through post secondary education participants[5]. The study broke the studies up into several major categories in their analyses, finding that concept maps aided in instructional goals and student learning in almost all situations, at all age levels, in all contexts. In particular, student construction of concept maps appeared to be very useful, although even just studying a preconstructed concept map led to some educational achievement enhancement. Working on concept map development also appeared to improve learning outcomes in collaborative learning and peer interaction exercises. The authors mention early in their work that concept maps may aid learners because verbal knowledge and mental images reside in separate but interlinked memory units. This is interested in light of Rich Felder's work on identifying the visual/verbal axis in his learning styles assessment materials[18-21].

Anecdotal information from the author's surveys of students over a 10 year period have revealed that about 90% of honors freshman at the home institution are visual learners, indicating that text only materials may not be the best way of fostering student learning, even among very high achieving students. A visual representation of connections between topics on a concept map is also easier in identifying links compared to scanning and re-reading text only materials. The authors of the meta study[5] go on to suggest that maps my be useful because they reduce the difficulties in placing new material into the context of pre-existing knowledge. This may be due to the visualization engendered by the representation of the material

The meta-analysis[5] points out there is a strong need for assessing learning outcomes beyond conventional free recall and research-constructed achievement tests, which are primarily multiple choice or short answer assessment tools. The authors suggest that more work should be done to examine how students learn with concept maps and their effects on higher learning goals, such as problem-solving transfer, application, and analysis.

How students use concept maps

From a learning perspective, concept maps may enhance learning when used to summarize information[5]. Maps may be good for acquiring main ideas but may do poorer at helping students acquire detailed or nuance-laden knowledge and this may have some interesting impacts on how concept maps can be used effectively. Additionally, maps may be easier to comprehend for learners who are studying in a non-native language, possibly enabling them to draw larger inferences quickly even with language comprehension impediments. This may have implications for engineering students where large numbers of undergraduates now come from overseas.

Hilbert and Renkl did one of the more involved studies of investigating concept mapping strategies as a method for students to integrate textual information about a new topic[22]. Thirty eight university students were asked to read a series of articles about stem cells taken from newspapers. They were then asked to verbalize some statements about them, asked to then make concept maps of the information from the articles using a software tool for 30 minutes, and then redraw the maps after rereading the articles. The students were then given a multiple choice test and an open ended question about stem cells. In addition, students took intelligence tests that were designed to assess their verbal skills and their spatial/visual skills. The authors correlated information to answer a series of hypotheses. This is one of the few prior studies that have looked at visual abilities as related to the use of concept maps. Sixty-three percent of the students in the experiment had not been exposed to concept maps prior to this exercise. Students, in general, had learning increases on the multiple choice questions after reading the articles and doing the maps regardless of their spatial or verbal skills. However, on the open ended integration question, visual learners scored higher.

Finally, it is interesting that in most concept map applications, students have been asked to either construct concept maps or have been asked to study content on them. To this point, there has been no work on actually using concept maps to foster development of problem solving skills in the context of real problems.

Approach in this Work

The author of this work has long been involved with exploration of educational techniques of fostering student learning in both breadth and depth of their abilities to reach mastery of material. The topics integrated so far have included use of web-based interactive problem solving tools on-line[23], enabling freshmen students to transition effectively to college[24], creating syllabi that foster communication among faculty and students[25], information literacy[26,27], integrating sustainability into senior design[28], and predicting sustainability metrics through quantitative measurements[29]. In addition, there have been other papers on the arguments for a straight grading scale in engineering[30], the balance between teaching and research at different institutions through a quantitative investigation of pedagogical publishing[31], and forming balanced teams through students' self assessments of their own abilities[32]. This summary is included here because some of the themes that have emerged over time bear on this work and show that creation of concept maps and their use is logical. The interfaces among the different educational topics will be discussed where appropriate. Much of the work on integrating new learning and teaching approaches was done to foster learning for students with different learning styles.

Felder and coauthors, as previously described, have long explored different learning styles for students and teaching styles of faculty and how those interact for student success[18-21]. In relation to this work, students who learn best from global approaches may find the use of concept maps useful in synthesizing a coherent framework on how new material is connected together. Sequential learners, the other end of the global-sequential continuum, may find that they can piece together longer chains of problem solving events when they can see more complex interconnections than sequential trial and error may allow them to experience. Visual learners may also find the map format more useful than verbal descriptions of connections. In the context of these learning styles, there have been three major uses of concept maps in courses taught by the author that will be highlighted using examples from the most recent offerings of each course.

Sophomore Material and Energy Balances

In the sophomore material and energy balances course, there were a total of 94 students who finished the course out of the 103 who began the course at the beginning of the Fall 2008 semester. This course is the first core course in chemical engineering and is one of the two options engineering management students must take in order to meet their energy-based curriculum content requirements. Students in engineering management may take this course during their sophomore, junior, or senior years, while chemical engineers will be sophomores.

A variety of instructional support tools were used in this course that had an impact on the use and evaluation of concept maps in student learning. These tools were primarily computer-based and included the use of Desire to Learn (D2L), a comprehensive tool for organizing course information and tracking student use of online content, the use of OneNote, a powerful software program that utilizes PCTablet technology to allow one to write on a virtual notebook page while archiving verbal statements made during class, and Microsoft Excel, Word, and Powerpoint files posted on D2L.

The primary use of concept maps in this introductory course was to facilitate student integration of new concepts into a coherent framework that allows them to solve complex problems. Because this class is oriented towards solving unique and new problems as opposed to being "plug-and-chug", this may be the first time that students are forced to integrate complex material at a deep level. Prior to each exam after the second exam, an integrated picture of interrelationships was constructed that showed how the complexity of the material grew while branches leading among disparate areas allowed one to handle more phenomena. Additionally, late in the semester, concept maps were used in the context of individual problems to help students organize the given information and begin formulating solutions. Samples are shown later in this paper.

Junior Equilibrium Thermodynamics

The core second thermodynamics course in chemical engineering at the University of Arizona contained 38 students who completed the course out of 39 who began the course in Spring of 2008. This course is in the fourth semester of core courses so students should be strong problem solvers at this point in their academic careers.

The concept map shown later was originally constructed by the author the first time they were the instructor for this course. In many institutions, the equilibrium thermodynamics course becomes a repository of topics that may not fit together into a coherent whole and the author struggled to synthesize the connections between the seemingly disparate topics. With the core relationships worked out, it then became possible to connect all of the material rationally while also building an end of the semester project that required students to use the interconnections between course content.

Senior Design
The senior level chemical engineering class in the Fall semester of 2008 had 36 registered students who began and completed the course. Senior design at the home institution has undergone many changes over the last several years[33], the largest change being the integration and distribution of sustainability and related topics into the senior design series. The third year after this integration was done, a concept map was constructed to help students see how sustainability of technologies and decisions could be affected by social, economic, technical and environmental issues. This concept map is shown later on in the results and discussion.

Results and Discussion

Concept Map Uses and Details: Figure 1 on the next page shows a sample of the concept map first included in the sophomore course lecture, drawn in real time with students generating the concepts that showed up on course objectives while the instructor linked the concepts together prior to an exam. The figure is a screen shot from the OneNote program which functions as a computer-based notebook where one can draw freehand or type in information. This concept map outlines the first five chapters of Felder and Rousseau's Elementary Principles of Chemical Processes[34] text typically used with beginning chemical engineering students.

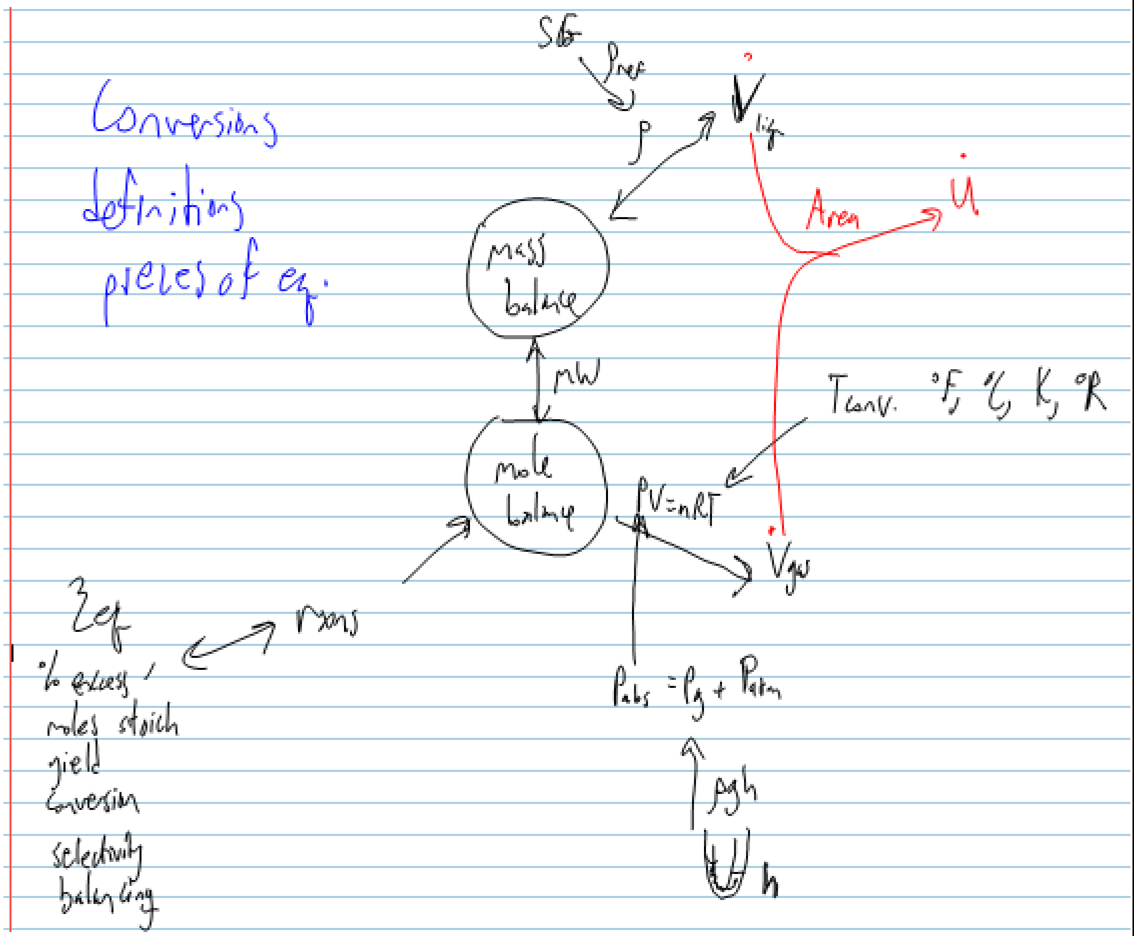

Figure 1 - A freehand example of a concept map drawn during class using the OneNote Program. Material on this concept covers almost all of the first five chapters of the text chosen for the sophomore material and energy balances course.

The concept map includes information about basic variable transformations like using specific gravity (S.G.) on the top of the diagram to convert to density (ρ) using a reference density (ρ_{ref}). Density can be used to convert from mass balances, represented in a circle as one of the fundamental cornerstones of the course, with volumetric amount of flowrate, represented as V-dot. In the center of the diagram, mass balances are connected to mole balances through the molecular weight (MW) link that interconverts between those two ideas.

In Figure 1, there are two major branches off mole balances. The one on the left labeled reactions (rxns) leads down to a laundry list of concepts and definitions that students should be familiar with from chapter 4 in order to be successful in problem solving. Another major branch leads down to the right from mole balances through the ideal gas law (PV = nRT). Some feeder information from the bottom of the diagram includes manometers, represented with the letter h for height difference between manometer fluid levels. This information is transformed through a gravimetric analysis (ρgh) to pressure, which can be used to relate gauge to absolute pressure through atmospheric pressure. It is absolute pressure that must be used in the ideal gas law. The ideal gas law can be used to convert moles to volumes for gases, often requiring some temperature conversions shown on the right side of the figure.

The final concept on the map is velocity represented with u-dot in the upper right of Figure 1. The velocity can be found from knowing the volumetric flowrates of either liquids or gases and the cross sectional area for flow. At this point in the course, students now had a concept map that linked the flow of information for different problems that can be covered using topics from chapters 1-5. In the upper left of the figure, there are some other concepts that overlay all of the problems and indicate core knowledge that must be assimilated in the context of the rest of the map. One needs to know how to manipulate unit conversions, how to use definitions properly, and how to understand what different pieces of equipment can do and how to model them.

Figure 2 shows how one can solve a simple problem using a concept map approach to indicate how information moves and in what order calculations can be done.

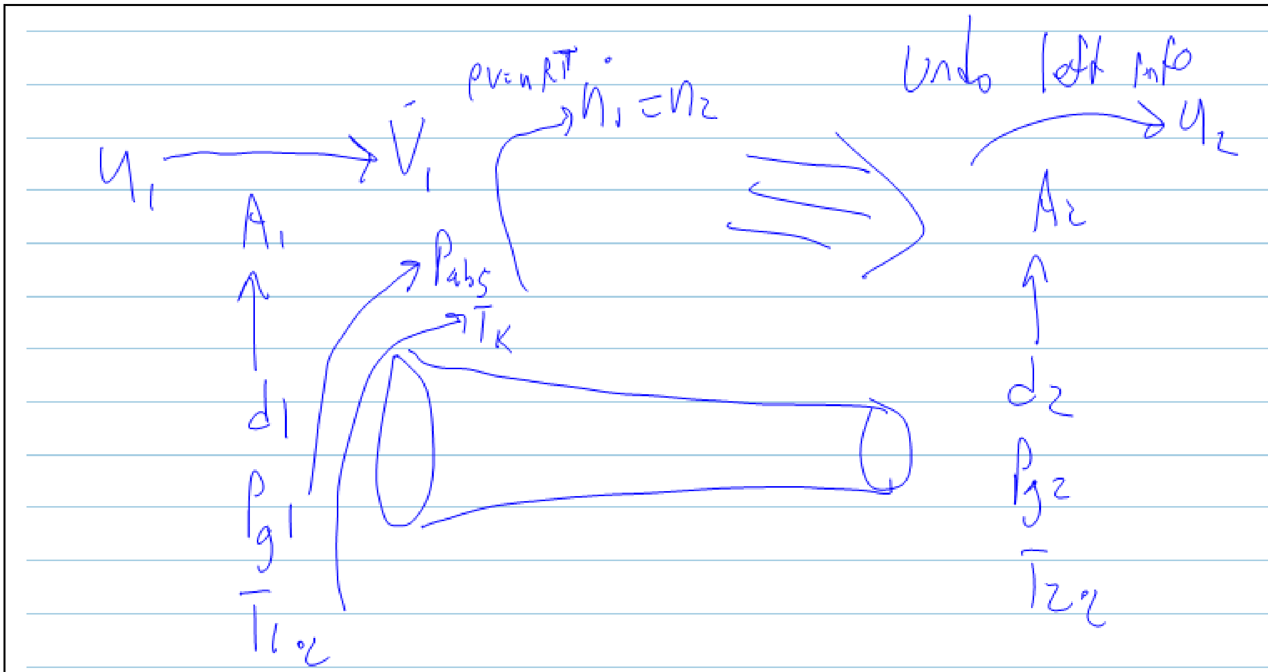

Figure 2 - A sample of how one uses a concept map approach to show how information flows through a problem where one is given an initial velocity of a gas into a certain diameter pipe, along with T and gauge pressure at the inlet and are asked to find the outlet velocity if you know the outlet diameter, temperure, and gauge pressure.

In the above problem, one is given the fact that a gas is flowing through a tube that has a decreasing diameter. The inlet and outlet conditions are given but students need to find the final velocity. Students need to figure out that they transform the given diameter of the pipe into a cross sectional area for flow, which is multiplied by velocity in the upper left of the diagram to get volumetric flowrate. In order to use the ideal gas law to get the number of moles flowing through the tube, one needs to convert the temperature to degrees Kelvin from Celsius and the gauge pressure to absolute pressure. One then uses the concept that the number of moles flowing into the tube must be equal to the number of moles flowing out of the tube. The entire right side of the diagram is then a pictorial representation of how the same information and calculations flow backward in a symmetrical way to yield the outgoing velocity. This concept map shows how a single problem can focus discussion on connection.

Figure 3 shows another example from 10-26-08 where a concept map was used in the sophomore course to show how information flowed through a problem towards an answer. The problem in this case is a classical example in chemical engineering where the inlet volumetric flowrate of a gas to an air conditioner is specified in addition to the temperature an pressure. The question then requires students to solve for the amount of water that would be condensed out from this air as it is cooled. The concept map shows that one uses the ideal gas law to find the molar flow (F_1) of the gas. One then uses the temperature to solve for the vapor pressure of water P_w* on the bottom of the figure. One assumes the total pressure (P_{tot}) stays constant and that only pure water is being condensed $x_{2,w} = 1.0$. This allows one to find the molar composition ($y_{3,w}$) of water in the exiting air using Raoult's law. At this point, one must solve two equations with two unknowns to arrive at the answer. This is typically a complex enough problem that many students will be lost by the end of the solution. In this instance, the problem was sketched and the equations were sequentially solved. After completion of the example, this concept map was drawn as a summary of the steps to connect the answer to the information stated in the problem.

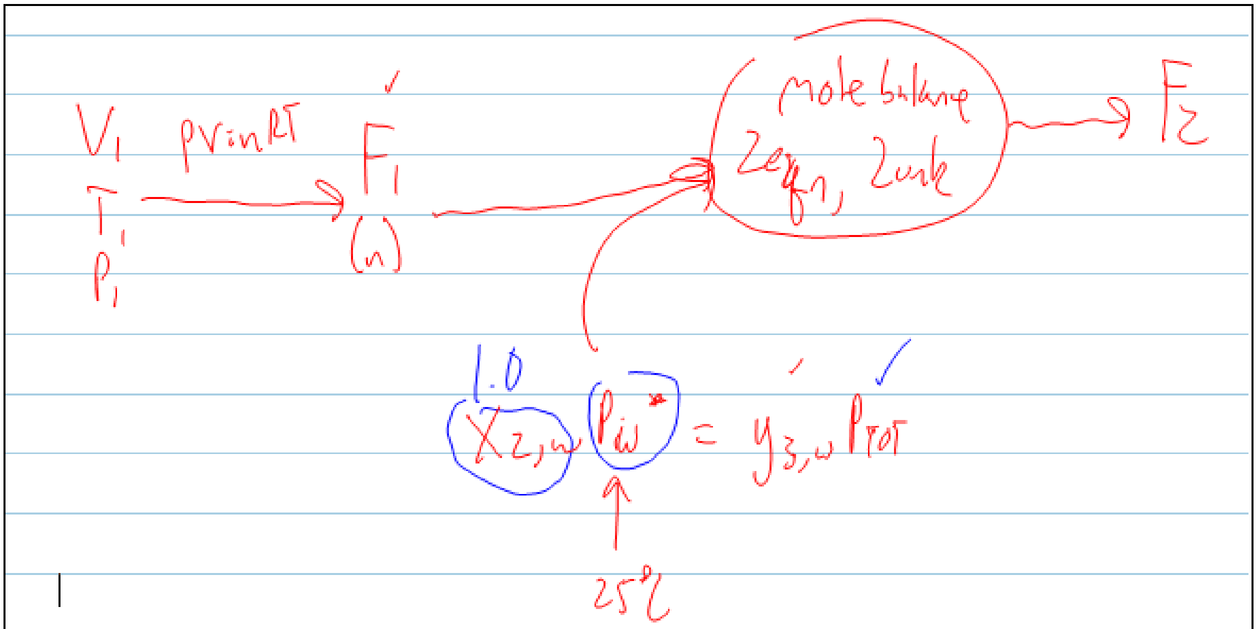

Figure 3 - A concept map for material from an advanced chapter that integrates material about equilibrium and Raoult's Law with a mass balance and ideal gas law using a single problem as an example.

Figure 4 shows a complete concept map for the entire course's material up through chapter 8 of Felder and Rousseau, which is the final chapter covered. One now sees that much of the information from earlier figures has been redrawn and that there is a new locus of connections on this diagram, which is for energy balances that are used to complement the mass and molar balances.

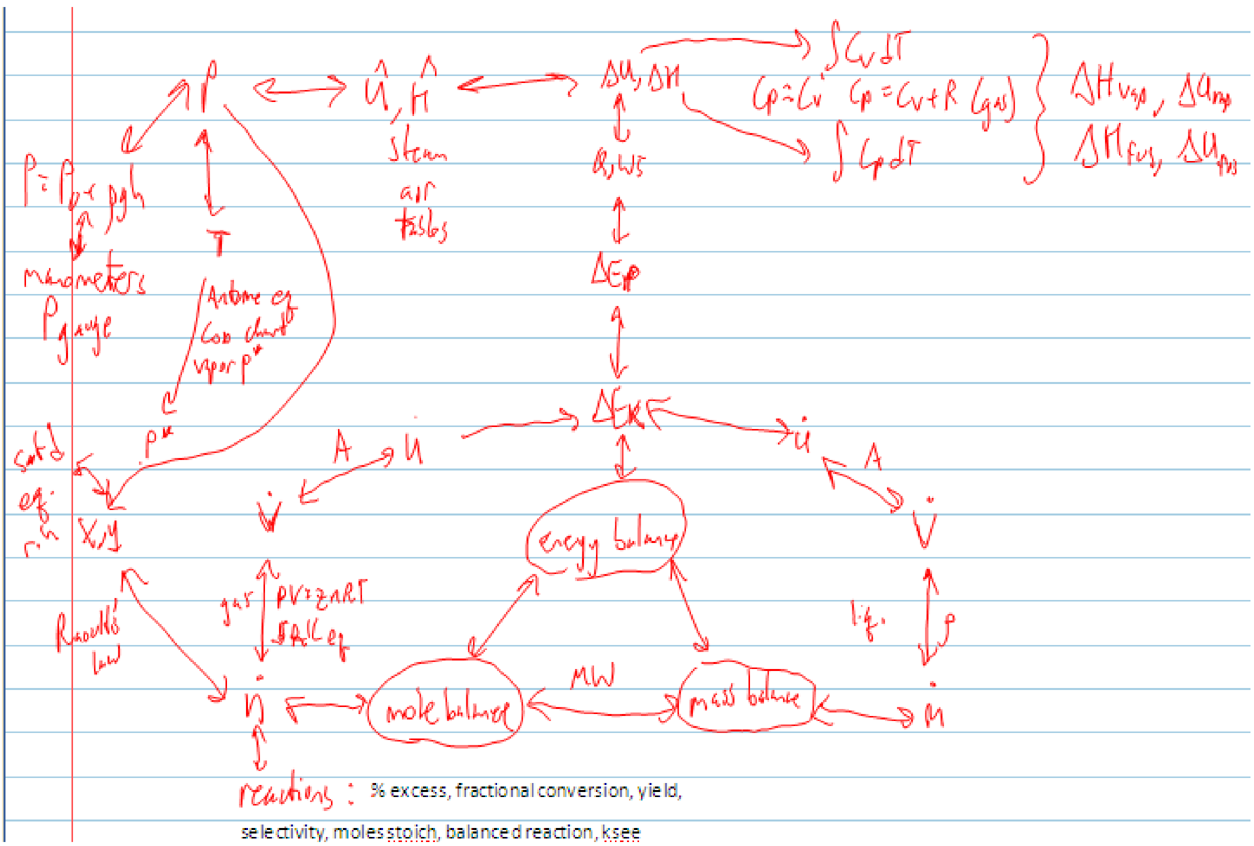

Figure 4 - A complete concept map for the first 8 chapters of Felder and Rousseau's book, including energy balances in addition to the previous material from earlier figures.

There are some more details that are included now. The addition of Raoult's Law seen in the previous example and the vapor pressures (P*) coming from Antoine's equation, Cox charts, or vapor P* tables have been added on the left near the manometer information. Some definitions regarding relative humidity (r.h.) and saturation (satd eq.) have also been added that lead to mole fraction concentration relationships (x, y), that then feed into moles and mole balances through the lower left portion of the diagram.

Energy balances appears as the third core concept in addition to mole and mass balances. And now, since there is some symmetry to the diagram to get from moles or mass up to velocities that then feeds into the kinetic energy term of energy balances, you end up with two pathways through volumetric flowrate using area to get to that point, one for liquids and one for gases. Potential energy, heat (Q) and shaft work (W_s) also appear leading up towards the top of the diagram where internal energy (ΔU) and enthalpy (ΔH) appear. One can then bridge over to specific internal energies and enthalpies (U-hat and H-hat) to the left through temperature and pressure information. One can also calculate enthalpies and internal energies from integrals of the appropriate heat capacities in the upper right. Phase change information may also be needed through ΔH_{vap}, ΔH_{fus} and ΔU_{vap}, ΔU_{fus}. It should be noted that even after several years of using concept maps in the course, the instructor still made three attempts to reach this final form that seemed most clear.

Figure 5 shows the same concept map as Figure 4, but now used in the context of a real problem solution. In this problem, students were given a feed rate to a boiler in moles/time, a cross sectional area for the feed, inlet temperatures and pressures and the fact that it was liquid water being fed. The outlet was at a higher temperature and lower pressure, causing the formation of a vapor after the valve (the piece of equipment in the process). The final velocity was also specified while the students were asked to find the diameter of the exiting pipe. This is a classical steam table problem in chemical engineering with a liquid entering and vapor leaving.

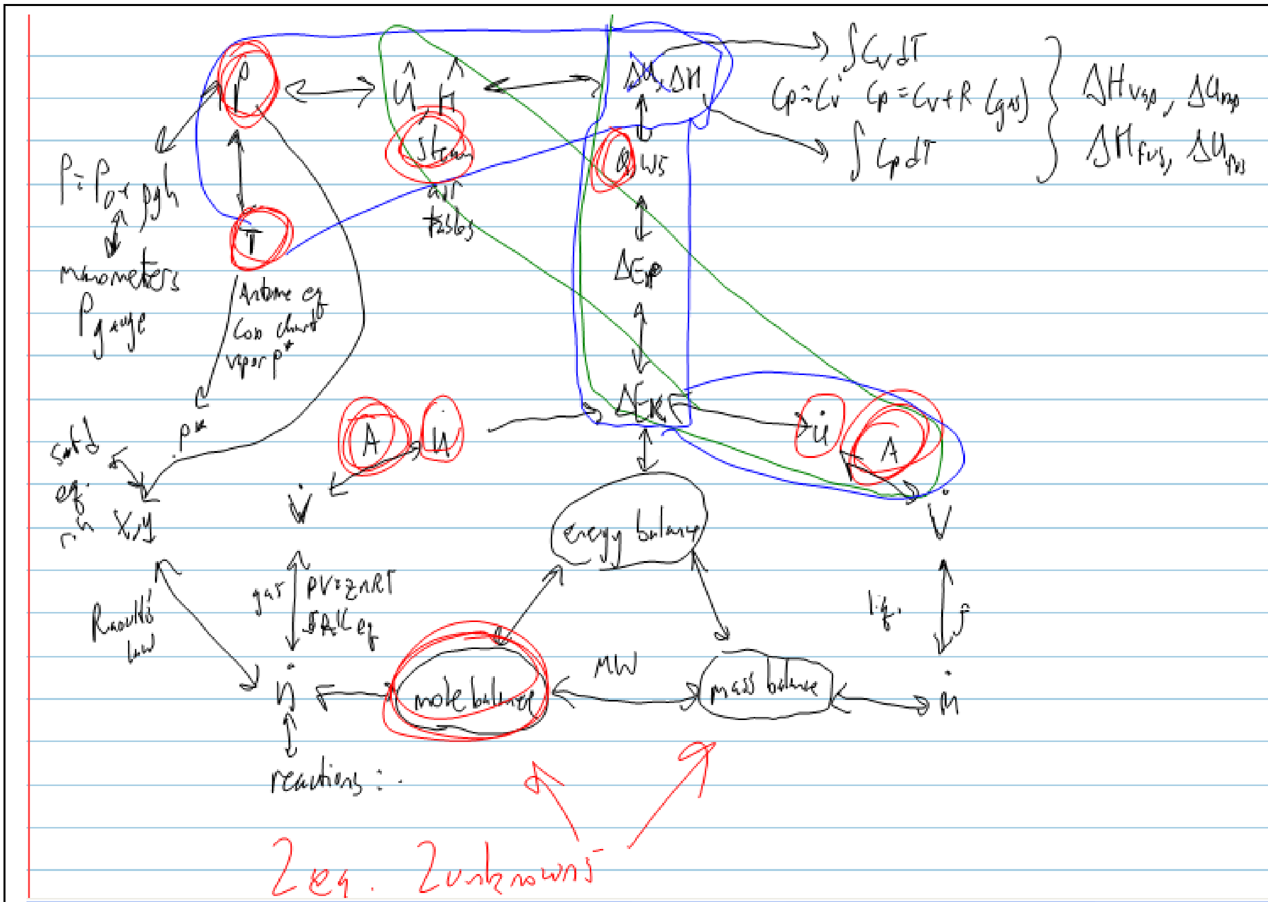

Figure 5 - A concept map used specifically in the solution of a complex problem. Red circles indicate information given in the problem statement and some student thoughts about solution steps. Blue and green circles highlight links students hypothesize to be important during the solution.

The first step in using the concept map was to circle all pieces of information from the problem statement and these circles appeared in red, as shown in Figure 5. With that done, students thought the problem solution could lead to 2 equations with 2 unknowns so a note was made of that comment (2eq. 2 unkonwns). Overwhelmingly, students thought mole balances would be the route to go based on their earlier experiences with problems already shown in this work that used the ideal gas law for an pipe diameter changing problem.

Students confident in their brainstorming of approaches to the problem that there would be an energy balance through the first law of thermodynamics represented in the central vertical list of ideas, including the fact that Q would be zero for an adiabatic system (circled in red). Two students thought that one could use the fact that steam/water vapor was involved to directly link velocity of the liquid and the cross sectional area through specific volume (V-hat and not listed on the diagram) through the steam tables, which ended up shortcutting the solution steps by about 5 or 6 manipulations. The discussion about steps and process was open to all students and there was much debate about the variables and how one could use them to get to the end point of area (A) and the diameter (not shown) for the gas in the middle part of the diagram. The author can comment that this was the first time a problem this complex was solved through presentation of a concept map in the class in addition to the problem statement where students drove the discussion. There was a lot of interplay among students as they discussed with each other what links led where and why some were not viable. This experiment of applying a concept map in a real time solution of a complex problem seemed to be a success as students brought copies of their maps to other classes and were annotating them and using them as starting points for exploring problem solutions throughout the rest of the semester.

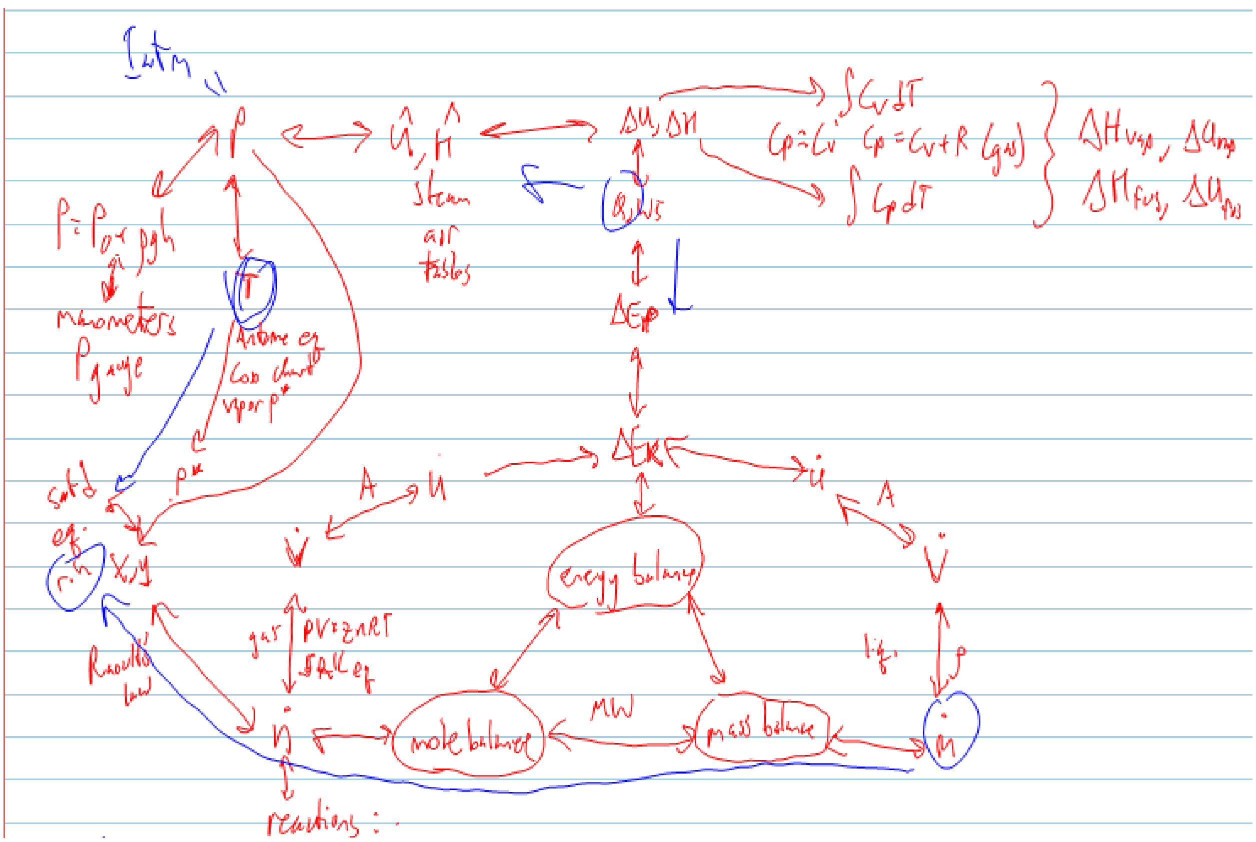

Figure 6 - A concept map representation of another classical chemical engineering problem of finding the mass of water needed to change the humidity of an inlet stream to a desired temperature and pressure. Given input values were circled in blue and hypothesized links of connections were laid out with blue lines this time.

Figure 6 above shows a concept map that is related to Figure 3 in that this is another problem involving Raoult's law around a piece of equipment. This time, students were told they had a humidifier and the flowrate of air in mass per time was specified in addition to the temperature and relative humidity. They were told the process was adiabatic and that water at a certain temperature as a liquid was added to the gas stream. The end result was a stream that had a specified relative humidity. The students were asked to find the final temperature and the amount of water that needed to be added to reach the desired relative humidity.

Based on previous problems and concept maps, students quickly realized there was an energy balance involving the adiabatic system where Q was zero. This then led them to the idea that enthalpies could be used (not shown on the diagram due to the pace of the discussion). However, the major thread of the solution went from mass in the lower right back through mole balances, through Raoult's law in the lower left, through relative humidity as a definition and then up to pressure were it was assumed to be 1 atm due to the system being open to the atmosphere. Students again argued back and forth about including some links over others before they solved the problem based on the concept map.

Leaving the sophomore class where the concept maps were used as problem solving tools and as prompts for review of material, concept maps can also be used to enable global learners, those who assimilate information in totality instead of sequentially, to get an idea of the structure of material and where new pieces will fit in as they are learned. Figure 7 shows a concept map handed out and then used during a junior equilibrium thermodynamics course.

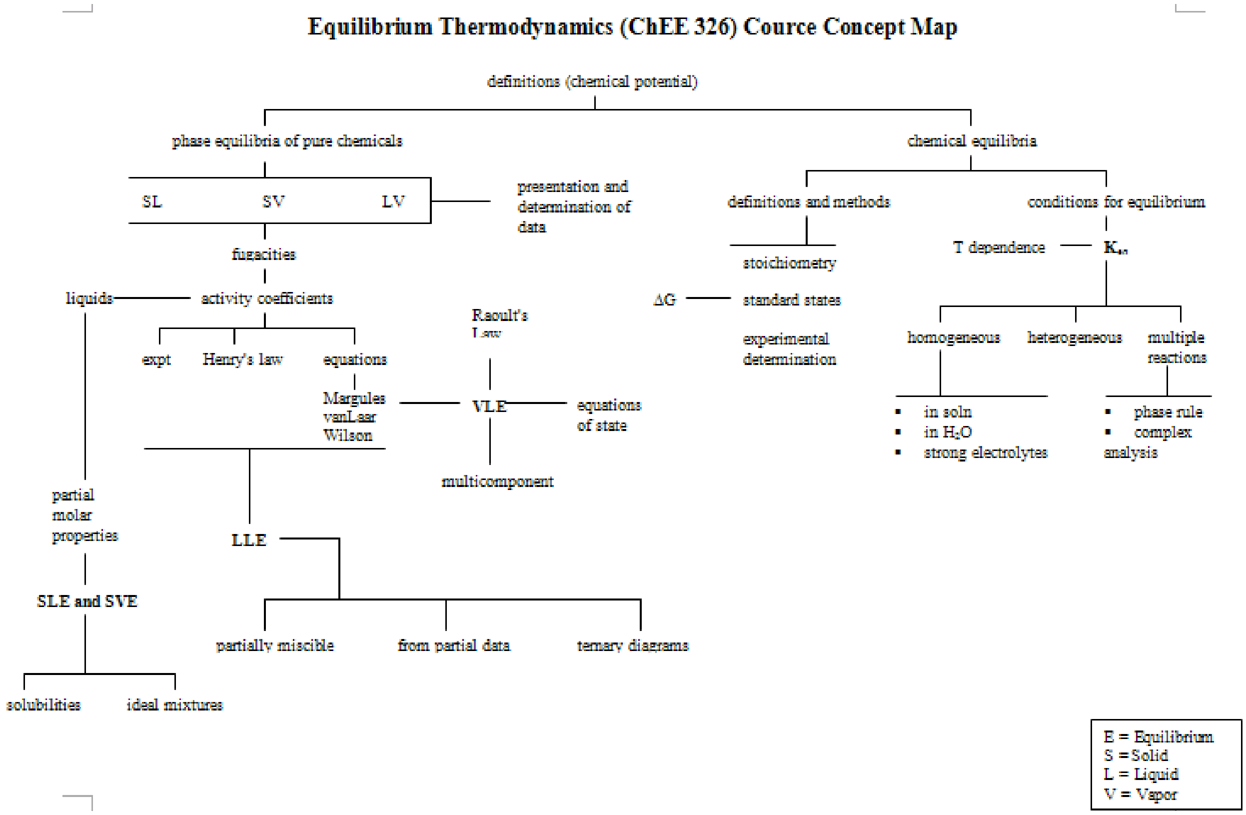

Figure 7 - A concept map used from the beginning of a course through the end to highlight how seemingly disparate parts of a course have an underlying structure.

In many chemical engineering thermodynamics courses, only the material in the upper left of the diagram is covered, particularly how to handle non-ideal vapor liquid equilibrium (VLE). In the course for this map, connections are made to liquid-liquid equilibrium (LLE) and solid-liquid equilibrium (SLE), in addition to solid-vapor equilibrium (SVE). The right hand side of the diagram shows that the very fundamental starting point of the class with definitions of equilibrium at the top of the diagram is the primary link to an entire second branch of reaction equilibria on the right side of the diagram. And within each topical area, there are details and subtopics that allow for greater investigation of different physical phenomena. The concept map in Figure 7 was used as a review tool before each exam in conjunction with the course objectives listed on the syllabus. The map was presented to students and students were asked to circle the parts of the diagram where homework had already been evaluated and returned, indicating to students what material was fair for coverage on the upcoming exams.

Prior to the creation of the concept map shown in the above figure, the instructor had experienced equilibrium thermodynamics as a series of disconnected modules with no common theme as discussed earlier. However, after creation of the visual map, they were able to conceptualize larger and more complex projects that would probe student understanding of the details in each area while sharing with them the power of the theories underlying the concepts.

Figure 8 shows a concept map used in the chemical engineering senior design course. Again, this concept map is furnished on the first day of class and then students are referred back to it as the co-instructors move back and forth among the different topics.

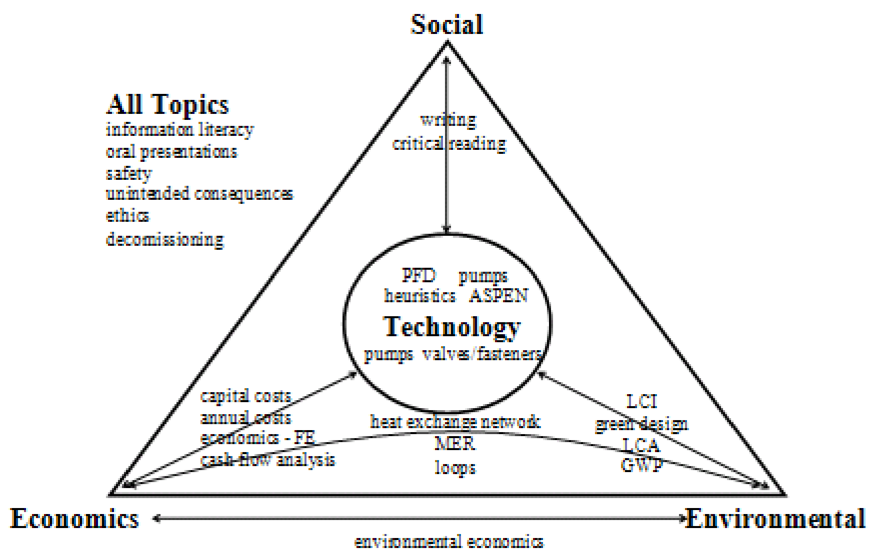

Figure 8 - A concept map for a chemical engineering senior design course where sustainability themes and topics have been interwoven into a more traditional course.

Sustainability, the ability to meet current needs without compromising the needs of future generations, has been included into a traditional chemical engineering senior design course in this case[33]. In the typical senior course, it is common to cover process flow diagrams (PFD), pieces of equipment, a simulation tool like ASPEN for chemical processes, rules of thumb for design, economics, and energy and material recycle strategies. A traditional course will also include oral presentations, writing exercises, and some elements of dynamics. Sustainability topics that have been included are life cycle inventory and life cycle assessment as tools of evaluating sustainability (LCI and LCA), global warming potentials (GWP), safety, unintended consequences of technologies and processes, and decomissioning of facilities and rehabilitation of industrial brownfields. Throughout the course, information literacy has been introduced as a way of using popular and peer reviewed media to organize decisions around quantifiably sustainable processes.

This concept map was created in the third year of the course's offering as an integrated one with sustainability. It is interesting because students during the first two years had often commented on their anonymous teaching evaluations that they did not see why the topics were even in the same course. Also, students had pointed out that the sequence of material was random to their eyes. Those comments were valid in that the instructors rearranged the material around travel schedules. However, after the creation and introduction of the concept map, students no longer questioned the ordering or connections among the material. They could see how one could move between the environment and economics through one connection of environmental economic theory and decision making, or one could consider making process modifications through minimum energy need analyses or by creating material recycle loops.

In this paper, we've shown how concept maps have been used in different ways. First, like some of the works in the introduction, concept maps have been used as review and summary tools.

Students were provided with a map or ones were generated in course discussions using objectives listed in the syllabi. Similarly, the concept maps in Figures 4, 7, and 8 show how connections among material can be provided to students as a guide that helps both global and visual learners. On the other hand, this work is the first one that explores the use of concept maps during problem solving as a way of exploring how information can be transformed and aggregated to lead towards the end goal of a problem solution. This use was highlighted in Figures 3, 5, and 6.

Two evaluation tools will be examined in this work to examine student use of concept maps and successful outcomes. One evaluation tool will quantifiably examine whether student access to posted lecture materials was more frequent on days when concept maps were archived. Another assessment will involve student self-reports of their use or usefulness of the concept map approach.

Quantititative Access of Archived Concept Maps:

The first analysis of student use involves combining data from the D2L course management software used in the sophomore course with the content of each lecture's posted content. The D2L tool allows the instructor to monitor who accessed files and on which dates throughout the semester. A review of all OneNote lecture files showed that a concept map was first included on 9-29-08 and included the first five chapters of material. On 10-10-08, another concept map with more layers of connections was presented in the context of solving one problem solution. On 11-26-08, 12-1-08, and 12-3-08, larger concept maps, including almost all content from the course, were used in solving problems.

One would expect that the dates with those lectures would be more heavily accessed than others if students were responding to the introduction and use of concept maps. Figure 9 shows that student access to materials did not track with the dates when concept maps were included in the archived material. Another work shows other trends in student use that more strongly correlated with access to the online materials[35]. These correlations include scheduling proximity to exams and the difficulty of the material. It is possible that future work could post concept map materials separately so better control over measuring what the students were specifically accessing would be possible. As the data stands, there may be multiple elements of a given lecture that led to the downloading of those materials over other lectures.

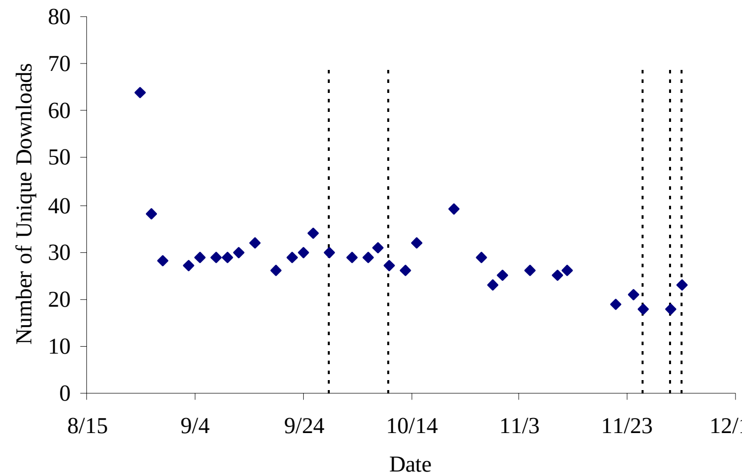

Figure 9 - A plot of the number of unique students who accessed online content throughout the semester compared to the verticle dashed lines which are lectures that contained concept maps.

Anecdotal Information about Student Use and Views of Concept Maps:
In addition to the attempt to quantify student use of concept maps compared to their posting in lecture notes, student anecdotal stories also provide some insight. One student in the sophomore course stated that the concept maps enabled him to see connections he normally would not have and he went on to ask for help in constructing a concept map for the organic chemistry course he was enrolled in. He was then provided with a sample organic chemistry concept map[1] encountered in the literature during the writing of this paper. He commented that the reactions were now falling into patterns for him as opposed to being unlinked.

Another student, prior to the generation of the final sets of concept maps in the sophomore course, filled in and connected the details of new material to the existing structure from lecture. He commented that the exercise enabled him to solve the more complex problems with regularity. In the end, he credited his success in the course to using the concept map on every problem.

A large fraction of the class had representations of the concept maps in their study materials allowed during the exams in the sophomore course, choosing that content over other information they could have chosen for the limited space available. While a formal count of this was not done, approximately half or more of the class selected concept maps as material they used during the exams.

The sophomore classroom environment involves many active learning techniques. These techniques often involve posing a question to students and then encouraging them to work on solutions either individually or in small teams. The faculty member circulates and answers questions while also prodding students who are not making progress. Many students brought concept maps with them to class after they were introduced and used them during these activities to search out connections that would enable them to solve problems.

In a prior year when concept maps were used in the sophomore class, one student went on to form a small group that organized their own concept map for another core course known locally as being extremely challenging with a high attrition rate. The student, who was a solid B student, and his team went on to receive the highest scores on the exams through their preparation of concept maps. They felt it was this outside connection drawing that enabled them to move to the level that was being tested in that subsequent course.

Similar to the sophomore class, juniors and seniors often referred to the concept maps when discussing which concepts were eligible for coverage on upcoming exams. These discussions would start with a list of course objectives and what was fair game and students naturally moved the discussion on their own to the concept map, often then asking questions about how the material was fundamentally linked together.

Future work should be done to more quantifiably measure how learning styles and the use of concept maps helps or hinders different subsections of student populations succeed in engineering problem solving. This would involve the students taking a diagnostic test that identified their learning style while then controlling access to, or training in how to use, concept maps. It would also be an interesting study to quantify changes in student attrition rates over time to see if concept maps may enable those students who normally would have left engineering to succeed.

Conclusion

This work discussed how concept maps have been used in many different disciplines, often with a subsequent raising of student performance as assessed through exams or other measures. An exploration of the use of concept maps showed that they had not previously been used during the problem solving process in order to reveal connectivity of topics to students. This work showed both traditional uses of concept maps and this new idea of using them to foster problem solving skills in the context of core chemical engineering courses. While student increases in performance were not measured in this work, the groundwork has now been laid for evaluating how integration of concept maps into curricula improves student performance in problem solving and problem syntheses tasks while possibly impacting student retention rates.

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Biographical Sketch

Paul Blowers received his PhD from UIUC in 1999 and has been a professor in chemical and environmental engineering at the University of Arizona since that time. He has been recognized as a top educator at the departmental and regional levels and in the past year was recognized as the best faculty academic advisor at his institution. He then went on to be selected as one of the top four faculty advisors in the U.S. by the National Association of Academic Advisors.