AC 2009-770: QUANTIFYING LEARNING THROUGH THE USE OF MIND MAPS AND CONCEPT MAPS

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Quantifying Learning Through the use of Mind Maps and Concept Maps

Concept Maps, Learning, Cognitive Science

Abstract

In this work mind maps and concept maps will be used to facilitate the process of learning by quantifying the ability of students to connect existing memories to new concepts. Research from cognitive and neural science indicates that learning occurs through the repeated process of storing, retrieving, and connecting information.

Aligning instruction with the way in which students learn is difficult. Instruction is often delivered using a topic-by-topic presentation of material because the instructor's expertise in a field, coupled with repeated application of concepts, facilitates this approach. Instructors are able to quickly and easily retrieve information because they have a vast network of neural paths developed through repeated use. Students, on the other hand, are faced with both establishing the connection of stored information to new concepts and strengthening the connection with repeated use. If the connection between retrieved information and the new concept is made, learning will occur—otherwise it will not. This research explores the use of mind maps and concept maps as quantitative tools to measure the learning process of students and to identify important missing connections between concepts.

Introduction

The questions which this paper attempts to answer are: how can mind maps, or concept maps, be used to assess the level of student conceptual understanding, and how can the information obtained through the evaluation of students be made use of to improve student learning and instructional methods?

Mind maps and concept maps, while similar in that they are both graphical representations of cognitive processes, are different in their structures and functionality. Mind maps consist of clusters of ideas emanating from a central topic using branching. Concept maps are graphical representations of knowledge using a combination of directed arcs and labels which link related information. Mind maps better facilitate spontaneity and creativity while concept maps better facilitate identification of relationships between constituents of a body of knowledge. Particularly important is the distinction that concept maps rely on the creator's ability to connect related information; mind maps do not require linking of any information.

Mind maps have been used to help students create visual representations of their thinking patterns in sociology[1], economics[2], and psychology classes[3], and they have been used as assessment tools in chemistry classes[4] and biology classes[5]. Engineering educators have likewise examined the use of concept maps in assessment[6,7].

Discoveries in neurology, brain science, and cognitive psychology are revealing more about the way learning occurs and the conditions that optimize learning. The brain is capable of rewiring and remapping itself through phenomenon neurologists call "plasticity". Of significance to educators is the fact that this process of rewiring and remapping is influenced by problem solving, thinking, creativity, and various other facets of education. The realization that learning must begin with what students know, not what instructors know, inherently puts students at the center of learning; i.e., all learning is student centered. From *How People Learn: Brain, Mind, Experience and School* [8] :

> A logical extension of the view that new knowledge must be constructed from existing knowledge is that teachers need to pay attention to the incomplete understandings, the false beliefs, and the naive renditions of concepts that learners bring with them to a given subject. Teachers then need to build on these ideas in ways that help each student achieve a more mature understanding. If students' initial ideas and beliefs are ignored, the understandings that they develop can be very different from what the teacher intends.

The statement that all learning is student centered learning is not a proposition of pedagogical theory, it is a physiological fact[9]. Diagnostic exams and enforcement of course pre- requisites lends insight into what a student does not know—not what he or she does know. It is difficult to ascertain what a student knows about a topic from a question that is answered incorrectly on a diagnostic exam. Unless specifically designed to do so, diagnostic exams are not capable of identifying the "connections" students have formed which enable them to recall and apply concepts.

Mind maps (and/or concept maps) provide a mechanism for a student to communicate graphical representation of the current understanding he or she has of a topic or concept. As significantly, if a student has an incorrect understanding of a concept it is important to identify and correct this misunderstanding as early as possible. This paper examines the use of mind maps and concept maps in facilitating deep learning with the future objective of quantifying and ultimately developing a parametric learning model. If it is possible to identify the most significant variables associated with deep learning, it should then be possible to control them with specific processes or rubrics. This paper is not an attempt to develop a "one model" fits all, but is an attempt to gain insight into how educators can better facilitate learning.

The notion of developing mathematical models to simulate and control learning has been explored by numerous researchers. Differential equations[10], the influence of prior learning, motivation, time on task[11] and empirical modeling using sequences of stimuli[12] are just a few of the models researchers have developed in attempts to quantify, and subsequently monitor and control the learning process. Given that learning is extremely non-linear it is not surprising that no single model has been consistently accurate in quantifying learning. Furthermore, neuroscientists have determined that learning is highly dynamic and that educators, through particular protocols, can promulgate changes in the brain in relatively short periods of time.[13] However the first step to ensuring that deep learning occurs is to make known the student's current understanding of a topic. Utilization of mind maps and concepts maps enables an instructor to acquire a visual representation of the understanding that a student has regarding a

specific topic.

Methodology

The methodology used to explore the questions this paper attempts to answer is divided into two phases. Phase 1 occurred over the period of a semester in two sections of a first year, required, engineering course. Each of the authors of this paper instructed a section of the course. Phase two of our methodology is presently in progress and is utilizing observations made in phase one.

Methodology: Phase 1

An introduction to engineering course was used to examine the conceptual grasp of first year engineering students for a set of topics that included statics, engineering economics, statistics, use of spreadsheets, and programming. With a single word used to describe the lecture topic, *statistics* for example, the students were given three to five minutes to freely associate with the topic and then record their thoughts on a mind map. Following the presentation of concepts, sample problems were presented followed by an in-class assignment requiring use of concepts presented in the lecture. After completing the assignment, students were instructed to add to their mind maps any information they felt would help them better remember and later apply the same concepts. This sequence of free-association by students, concept development by the instructor, worked sample problems and an in class assignment was repeated in class throughout the semester.

One section of 32 students was instructed to make mind maps using paper and pencil and these students were required to submit their mind maps prior to leaving class. The other section's 29 students were instructed to use FreeMind[14], freeware for mind mapping, and were permitted to submit their maps after class but before the end of the day. Systematic content analysis included a rudimentary measure of complexity by counting the number of nodes on each map as well as noting whether students chose to represent their thoughts using words or symbolic notation.

Prior to the second of two regular semester exams and the final exam, research instructors constructed mind maps to be used as the exam keys. Faculty members teaching the same class, but not using mind maps, were asked to review the keys and state whether or not the mind map adequately reflected those course concepts on which students would be tested. Following editing of the mind maps to reflect faculty consensus on the concepts to be tested, the exams were administered and graded using the mind map key.

Results and Observations: Phase 1

- *Observation 1: Students constructed their mind maps in a manner consistent with the consequences of rote learning: the production of information for extrinsic reward.*

Although students were instructed to begin each topic with free associations which they would use as "stepping stones" to new concepts, the tendency of students was to construct the maps for extrinsic reward, i.e., students wanted to know that their maps were "correct." In spite of instructor efforts to emphasize that the maps are unique to each student, students persisted in producing maps based on their perceptions of instructor expectations.

- *Observation 2: Instructors and students chose significantly different types of information to include on mind maps.*

Instructors' maps organized information in a concept "centric" fashion, whereas students' mind maps took on an organization centered more on collections of ideas or application. For example,

free associations with "statistics" prompted results from students such as "sports", "average", and "trends". These associations with the topic of statistics make perfect sense and are easily understood in the context of statistics. However, the concepts of variation, central tendency, correlation, i.e., fundamental concepts of statistics are not associations first year students make, nor would be expected to make, with the topic "statistics."

- *Observation 3: Instructors and students organized the information on their maps in significantly different ways.*

Student mind maps generally reflected ideas with lines emanating from only the central topic, i.e., "sibling" nodes were predominate and "child" nodes, second generation ideas, were meager. The single exception to this observation was when students were asked at the start of the term to use mind maps to convey personal information. In Figure 1, analyze the data, check work, and make sure units are correct are *children* of analyzing. Analyzing, theory, brainstorming and solution are *sibling* nodes.

- *Observation 4: The maps of students using symbolic or pictorial representation of ideas did not produce maps as complex as those students choosing to use words or phrases.*

The number of child nodes on the maps of students choosing to express their ideas with words or phrases tended to be greater than those of students who chose to express their ideas using graphics or equations. The authors noted that students with more complex maps were more likely to be top performers in the class.

- *Observation 5: On those maps of students including several child nodes, the nodes tended to be serial rather than branched. Branching, which the authors postulate reflects deeper learning, was not prevalent on student maps.*

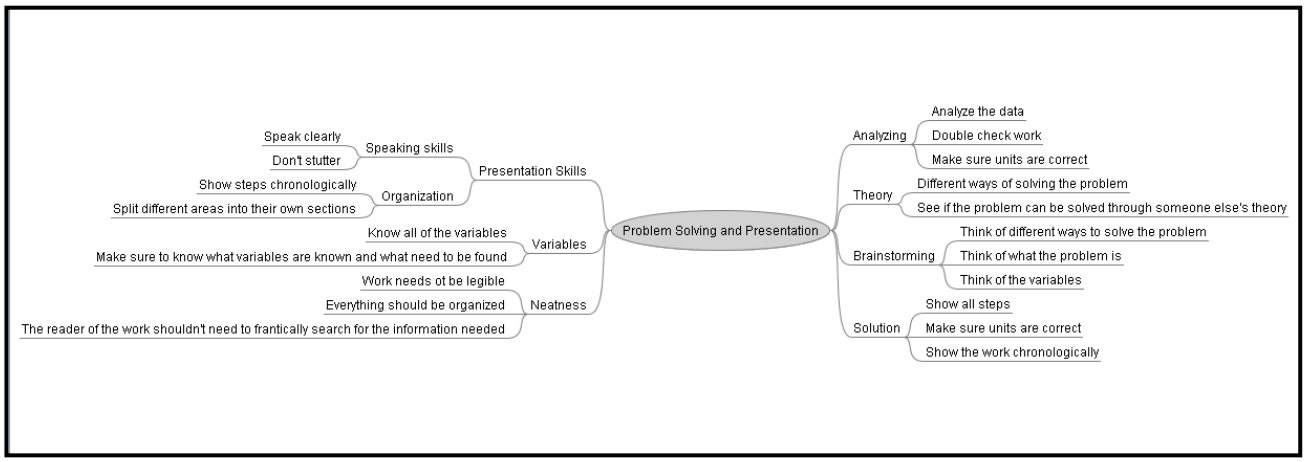


Figure 1: Student generated mind map on the topics of problem solving and presentation

Stylistic preferences, verbal efficiency, and the use of symbolic notation made a consistent measure of complexity by simply counting nodes difficult. Nonetheless, data from several maps was collected and recorded with as much consistency as possible. Regression analysis on this data did not produce meaningful results or discernable patterns.

While use of mind maps to construct exam keys helped improve uniformity in grading, they were not found to be insightful in terms of how students learn. Among the reasons for this outcome: 1). Mind maps do not facilitate identification of the "missing" connection between what the student understands about a concept and the concept itself. 2). Students did not utilize their

mind maps as a means of helping them identify and associate concepts with what they were learning in class. For example, in learning to program, the concept of "branching" and "repetition" seldom occurred on the mind maps of students, although the knowledge of *if-then*-statements and *for-next-loops*-was frequent. 3). Pedagogical models that inculcate rote learning are prevalent and difficult to contravene; students are familiar and comfortable with these models.

Should it be demonstrated that mind mapping is an accurate visual representation of the physiological process of learning, there is much to be gained with further study of the distinction between the construction of mind maps by instructors and their students.

While mind maps are useful because they are a free-form representation of student thought, they, for the same reason, present the following challenges:

- Numerical models are difficult to develop for mind-maps.
- Students may be unable to represent their actual understanding with key words.
- Students may be able to organize information around a central topic, but this representation of information does not indicate mastery of the material.

In an effort to address these problems the authors determined that concept maps, rather than mind maps may prove to be more useful in answering the questions of a) how can mind maps be used to assess the level of student conceptual understanding, and b) how can the information obtained from student evaluation be used to improve student learning and instructional methods? Concept maps, rather than beginning with a single idea or topic begin with a "focus question". Furthermore, concept maps promote the development of a student's understanding by requiring them to "link" one idea to another with a single word or phrase. Mind maps tend to encourage the generation of ideas, while concept maps encourage the linking of concepts. Furthermore, concept maps are defined as tools for organizing and representing knowledge[15], and researchers have found that concept maps encourage "students to use meaning-mode learning patterns."[16] Additionally, concept maps exhibit characteristics that are not possible to exhibit with mind maps. Novak and Cañas[17] define a concept as a *perceived regularity in events or objects, or records of events or objects, designated by a label* and identify the following as characteristic of concept maps: concepts are represented in hierarchical fashion and relationships are included that facilitate linking from one domain of knowledge to another. The National Research Council's Committee on the Foundations of Assessment[18] points out that the findings from cognitive research cannot always be easily put into practice. Because concept maps were founded[19] on principles of brain science and cognitive psychology, and because they are unique to the person producing them, some formerly difficult to implement findings from brain science may be made easier with the use of concept maps. Phase II of our methodology evaluates student mastery of concepts and implements the use of concept maps in a thermodynamics course.

Methodology: Phase II

A sophomore level thermodynamics course is being used to examine the ability of students to master a key set of concepts and ideas, be able to perform specific tasks related to

thermodynamic calculations, and the ability to combine the concepts and skills to solve new problems. It is the opinion of these authors based on teaching thermodynamics repeatedly that with a relatively small set of concepts and skills, students are able to solve any problem in their textbooks. While specific skills are easy to test for, the difficulty lies in determining which concepts the students have mastered throughout the semester. Concept maps are being used as a tool to measure the relationships students form between a given set of terms, ideas, and concepts.

Methodology: Phase II - Individual Concepts and Skills

In thermodynamics, students keep track of mass, energy and a property known as entropy, to examine and evaluate cycles. With a mastery of a few basic concepts, students can evaluate power, refrigeration, and heat pump cycles to explain the operation of air conditioners, refrigerators, power plants, diesel and jet engines, and many other mechanical devices. They can also determine how good these systems are compared to the ideal systems. Students must master the tools and concepts shown in Figure 2 in order to be able to successfully solve the problems in this course.

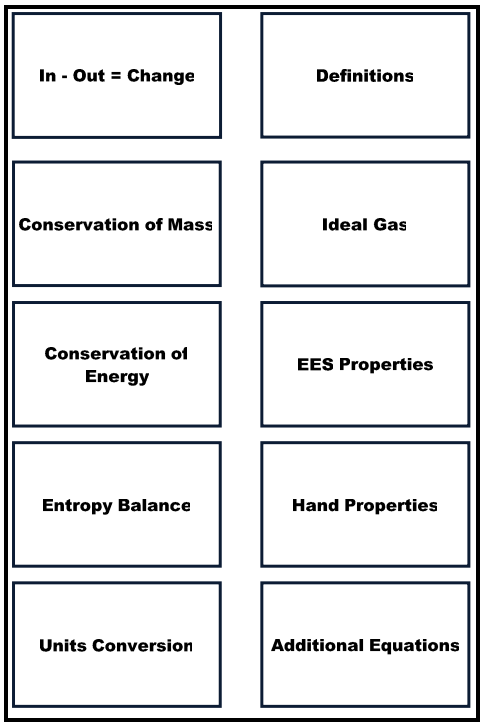


Figure 2. Thermodynamic toolbox

To determine the understanding a student has of each concept, problems are devised to gauge the level of concept mastery. Students are introduced to each key concept by viewing a 5 to 15 minute video before class, and whenever possible, students must attempt to apply the concept to something new while they are in class. Homework, quizzes, and tests are used to record individual grades for the mastery of specific concepts and skills on each assignment.

Results and Observations: Phase 2 – Individual Concepts and Skills

- *Observation 1: Many students subsist by learning a procedure for solving thermodynamics problems rather than through an understanding of problems based on concepts and skills.*

The following assignment was given to test the In-Out=Change concept.

A cooler (see Figure 3) contains within it a plastic bag filled with 0.5 kg of ice at 0°C that is floating on top of 1 kg of water at 25°C. The ice bag is opened and the ice is dropped into the water. If the control volume is the cooler, find the change in energy for this process.

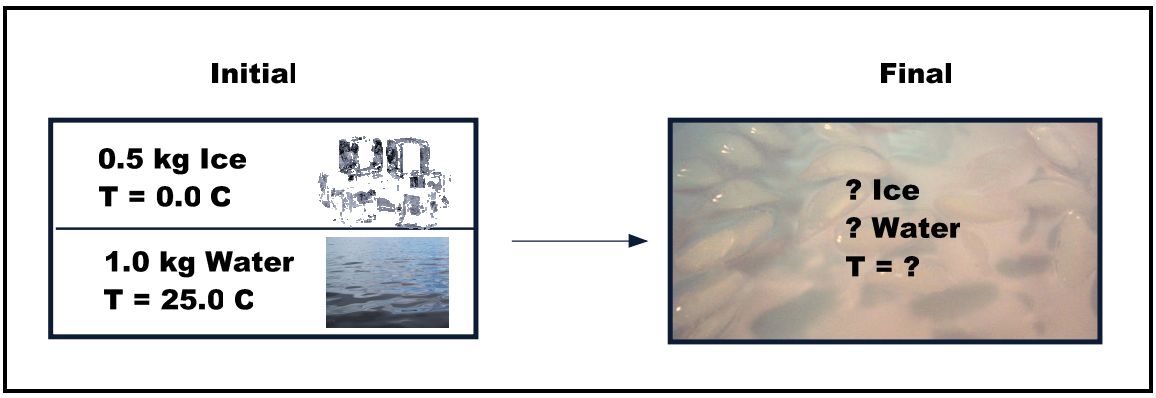


Figure 3. In-Out = Change, Assignment

In this example, the idea needed is that energy can enter or leave a control volume ,the cooler in this case, by heat transfer, by work, or with mass. No mass enters or leaves the cooler, there is no work done, and if the cooler is well-insulated, there is no heat transfer. In other words, no energy enters or leaves the control volume, which means that the change in energy is zero. The ice and water mixed together have exactly the same amount of energy as the separated ice bag and the water at 25°C.

Energy In = 0

Energy Out = 0

Change in Energy = 0

Energy In - Energy Out = Change in Energy

0 - 0 = 0

As with all thermodynamics problems, students typically reach a point of information saturation, in that they cannot absorb all of the information at once in order to solve a problem, and they cannot see the entire set of steps needed to completely solve a problem. Students spent up to an hour on this example problem, some indicating that it was a "trick" problem. Frustration ensues because they do not start with simple concepts, instead they fixate on what they do not know. At this point in the course they have not been taught how to calculate the energy of the ice or water. The purpose of problems such as this is to teach students that an energy balance on a control volume is essential for every thermodynamics problem that is encountered, and that this process is as simple as keeping track of how energy enters or leaves the control volume. For this

homework problem, 53 out of 58 students were able to correctly identify that there is no change in energy. This result indicates that students understand the necessity of performing an energy balance, but does not indicate that they will recognize the need to do so for subsequent problems, as is necessary for deep learning, which will be demonstrated later in this paper.

Three weeks into the class, a teaching moment arises during a 15 minute quiz. Students have become comfortable with a specific procedure, reinforced by the books procedural solution methods, and are faced with a problem for which that process does not work, i.e., the cooler problem. Students are asked to write the equation for conservation of energy that could be used to solve for the final temperature when the ice and the water are allowed to mix. A surprisingly small number of students (4 out of 51), during a 15 minute quiz, were able to write conservation of energy correctly. One student challenged the instructor, stating that "there weren't any problems like this on the videos that they had watched." In other words, they had not had to solve this exact problem before (regurgitation), and the student had not memorized a process to solve this problem. The correct equation is

$$0 = m_3u_3 - (m_1u_1 + m_2u_2)$$

This equation says: the final energy, the energy at state 3, is the same as the initial energy at state 1 plus the initial energy at state 2. The only new concept added to the initial cooler problem is that the amount of energy that mass has is the mass (m) times the internal energy (u) at each state. The final energy after the water and ice mix and reach equilibrium at state 3 is equal to m_3*u_3. The initial energy in the ice at state 1 is m_1*u_1 and the initial energy in the water at state 2 is m_2*u_2.

While typical students of thermodynamics may be able to use a memorized process correctly for many problems, they do not actually understand what they are doing and there is very little learning involved in this process, little deep learning at least. Tests which measure a student's ability to repeat a process are a poor measure of deep learning.

Methodology: Phase II - Putting Concepts Together

The challenge is to continually present students with new problems that can only be solved by application of a few simple concepts. This reinforces their use of key concepts, and that these concepts can be used to solve *any problem* in their textbook. By the end of the course, we hope that students will start with concepts, rather than a procedure, when confronted with a thermodynamics problem.

Besides specifically grading and recording assignments based on concepts (recording in-out=change, unit conversion, ideal gas, etc., for each assignment) and supplying students with new problems that challenge their understanding of concepts, the development of students can be gauged by comparing the relationships between their words and ideas to those of the instructor, who has a much better grasp of the "big picture", or how these ideas fit together and relate to thermodynamics. This type of comparative analysis is accomplished through the use of concept maps. In addition to directly measuring the grasp each student has on a concept, we can study the way in which he or she chooses to organize concepts on a concept map. Students' concept

maps are analyzed using Cmap Tools[20] and compared with the instructor's concept maps. Cmap Tools is freeware developed at the Institute for Human and Machine Cognition (IHMC) that enables its users to construct and share concept maps. Cmap Tools uses constructions first associated with concept mapping by Novak (1977, 1978). Cmap Tools is equipped with an analysis tool which facilitates comparisons between two concept maps. Linking phrases, key words, concepts, and propositions are among the comparisons that are possible with the Cmap Tools analysis utility.

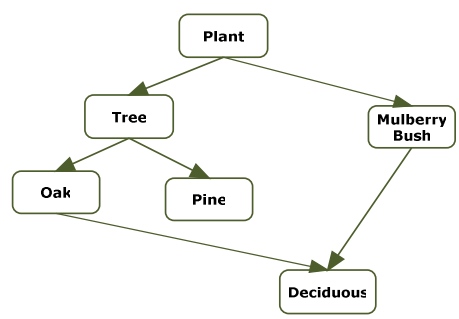
Results and Observations: Phase 2 – Putting Concepts Together

- *Observation 2: Students that memorize a procedure do not have to make relationships between concepts and ideas when solving problems. A concept map is a useful tool to see how students are organizing concepts and ideas.*

Shown in Figure 4 is a concept map constructed for the focus question "what is a plant?" This example was done for the purpose of demonstrating concept map construction. The second half of the assignment asked students to make a concept map for topics related to thermodynamics. The instructor's concept map for "what is a plant" is fairly organized and logical, however note that there is an error in the instructor's logic because a mulberry bush is actually a tree. A more knowledgeable person would have known this distinction and would have a slightly different concept map, demonstrating how concept maps show both organization and understanding.

You are to connect a set of words in a way that makes the most sense to you.
As an example, connect:

tree
oak
pine
plant
mulberry bush
deciduous



Logic:
Both trees and bushes are plants.
Two types of trees are given (oak and pine)
Both the oak and the mulberry bush are deciduous

Please connect the following sets of words or concepts in the way that best makes sense to you
starting with In-Out = Change

In-Out = Change
Air
Closed system
Conservation of Energy
Conservation of Mass
Heat Transfer
Ideal Gas
Internal Energy
Open System
Power
Refrigerant
Water
Work

Figure 4. Concept map: "Thermodynamic Terms"

For the thermodynamics concept map, there is a more complicated set of terms and ideas, so organizing the concepts often involves both a fine distinction in meaning as well as an understanding of how the concepts are related to each other and how they are applied to thermodynamics problems. Student and instructor concept maps are shown in Figure 5.

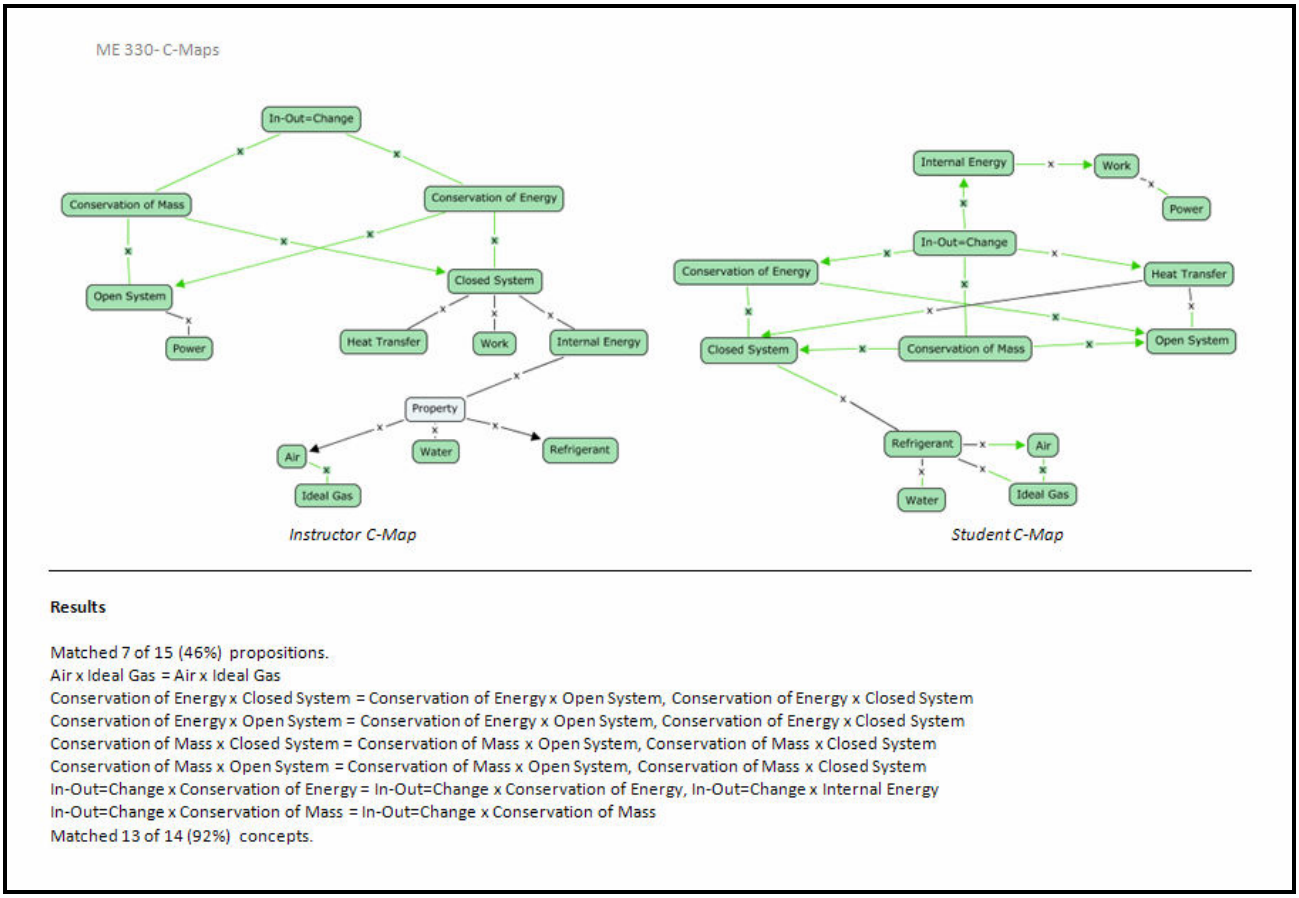


Figure 5. Comparison of instructor and student concept maps.

The instructor concept map is based on the following logic. A balance is performed (in-out=change) for both mass and energy; this is done for open and closed systems. For closed systems, heat transfer, work, and internal energy are of interest. Internal energy is a property. Properties of air, water, and refrigerant are found. Air is treated as an ideal gas. For open systems, the rate of work is calculated, which is called the power. Properties for open systems are also needed, so there should probably be a link between open system and properties on the instructor concept map.

On the student concept map, there are a couple of ideas that do not agree with the instructor's knowledge. The student connected refrigerant to ideal gas, when refrigerants do not, in general, act like an ideal gas. The student also connected work and power. Energy and work are needed to evaluate closed systems, and the rate of energy and power are needed for open systems.

These concept maps were introduced in week 3 of the course, so the instructor is not overly concerned about some of the differences, other than wanting to see improvement in the student

concept maps throughout the semester.

Expected Results

The same concepts are used throughout the semester, so the percent mastery for a concept is determined for every student throughout the semester, providing feedback for the student and instructor. Customized homework is used for students that need additional practice to master a particular concept.

The student organization of material (definitions, concepts, etc.) is addressed periodically through the use of a concept map, which provides information on the ability of students to understand how individual concepts relate to each other, and how they are applied to thermodynamics problems.

Data will be kept on common errors or misconceptions. Ideally, the instructor will have a database of these misconceptions and can refer students to the video where the concept was originally presented, and provide additional information and activities. The instructor must be careful not to simply provide solutions; the student needs to struggle with these concepts in order to sort through, organize and understand them in a way that make sense to him or her.

With numerical evidence for the level of student understanding, instructors can investigate specifically which activities/assignments allow students to grasp key concepts. A system of checks can be put in place to challenge and encourage students who are interested in mastering the key concepts. Timely feedback for both the instructor and student will further encourage deep learning, which should become increasingly apparent with the production of more complex and better organized concept maps.

By the end of the course, we hope that students will start with concepts, rather than a procedure, when confronted with a thermodynamics problem, and that this will enable them to solve new problems beyond the scope of the course.

Future Work

Findings from the research described in this paper will be used to examine the effectiveness of concept maps in facilitating deep learning. Furthermore, it is anticipated that results from this work will yield insight regarding those parameters that influence deep learning most significantly. If furthering the understanding of the mechanisms of deep learning is accomplished, subsequent effort will follow in developing the means for monitoring and controlling deep learning. Finally, pedagogical techniques such as those described by L. Dee Fink as "significant learning experiences"[21] can be superimposed on concept based learning to further understanding of the added benefits of combining concept based learning and holistic pedagogy.

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