Demonstration of Concept Maps to Enhance Student Learning in an Engineering Course

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Abstract

Due to the drastic shift in the educational landscape toward outcome-based learning, it has become essential to implement classroom tools that will facilitate better learning of the subjects that most students find difficult to grasp. This task seems to be even more difficult in engineering courses where concepts, terminology, equations, formulations, and problems, which are initially foreign to students, abound. This paper is an attempt to demonstrate the utilization of one of the tools of outcome-based learning that will accommodate a variety of learning styles, namely a concept map. The course selected to apply this tool is the first thermodynamics course taught at Southern University. This course is usually a one-semester course taken by third-year engineering students. The course is an introduction to the basic laws of classical thermodynamics and the behavior of gases and vapors. The principles and laws necessary for energy transformation are also covered. These concept maps are developed in hope that the student will be able to qualitatively and quantitatively grasp the fundamentals and how they are linked, and appropriately apply them in the analysis of engineering systems.

Introduction

One of the key elements to becoming a capable engineer is to be able to visualize a given problem. One body of thought is to (1) seek understanding of the problem, (2) formulate a written description of the problem, and then (3) formulate a method, procedure, or schematic to solve the problem. However, many engineering students find it difficult formulating a solution.

For basic and elementary type problems, determining a solution procedure may not present a formidable challenge. But in mid- to upper-level engineering courses, this step seems to be more of an obstacle. For many of these courses, only a few fundamental physical laws exist, but there are many variations of these laws when it comes to correctly applying them. This fact is apparent in the first thermodynamics course, MEEN 300, taught at Southern University. This is a one-semester course taught mostly to third-year students in Engineering.

Upon careful inspection and analysis of this and other engineering subjects, it is observed that the basic laws used to describe some physical phenomena are usually represented by one or more governing equations. These equations are usually valid within some region of space, and the limiting edge of this region is known as the boundary of the domain. In some cases these governing equations have some initial and/or boundary conditions (i.e., constraints) that must be satisfied by the proposed solution.

For example, if a gas such as nitrogen (N_2) is initially in a quasi-equilibrium state at a certain temperature and specific volume and is stored in a rigid container with a valve connected to it, the ideal gas equation can be used to predict the pressure within the container to a certain degree of accuracy[1]. For this case the walls of the rigid container act as a physical boundary for the substance and the mathematical boundary for the problem. It may be appropriate to use the ideal gas equation for the prediction of the N_2 pressure within the container walls, but not necessarily outside of the container. Hence, the space within the walls of the container represents the problem domain. Now, if the valve on the container is released so that a certain amount of the N_2 substance is allowed to escape, then other equations, such as the mass and energy balance equations may need to be used to predict the behavior of the gas. For a case such as this, these governing equations are constrained by the initial conditions given when the substance was at the quasi-equilibrium state.

In academia, once a written description of a problem is given or created, the solving of the problem can be viewed in two stages.

Stage I: Formulation of a procedure for solving the problem, wherein the determination of the governing equations and constraints are considered a part of this step.

Stage II: Performance or execution of the required mathematical steps to solve the governing equation(s) using the specified constraints for the desired unknown.

It is from this problem solving perspective that the forthcoming concept map has been created. Furthermore, the goal or rather "slant" of the presented map is to assist the student in the formulation stage (Stage I) of the solution process.

Kyaw Aung[2] describes the integration of computational tools, in an engineering thermodynamics course at Lamar University, in order to emphasize the design and analysis phases of the curriculum. However, many engineering students find it very difficult formulating a solution procedure to solve engineering problems. It is therefore imperative that engineering educators incorporate some tools of outcome-based learning in order to accommodate a variety of learning styles. So far there is limited information about concept maps applied to learning in engineering courses.

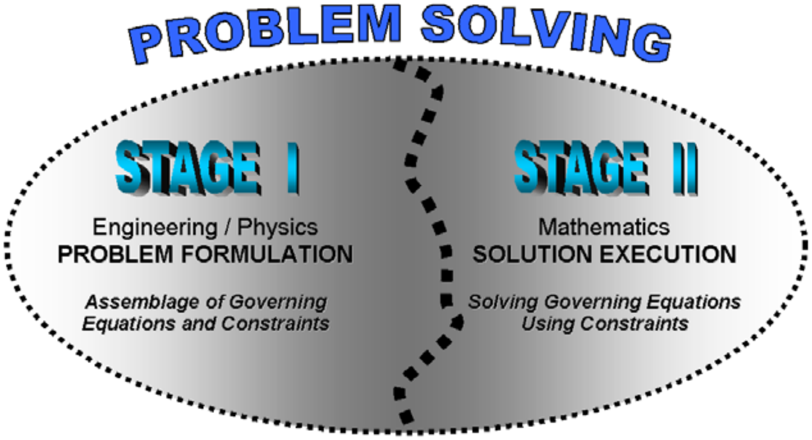


Figure 1. Depiction of the Perspective Taken in Problem Solving.

Concept Map Development

Course Description

The MEEN 300 (Thermodynamics I) course at Southern University is the first of two courses that covers the topic of Thermodynamics from an engineering perspective. MEEN 300 provides an introduction to the basic laws of classical thermodynamics and the behavior of gases and vapors. The principles and laws necessary for energy transformations are also covered.[3] Four basic objectives have been developed for the course:

Objective 1. Introduce the principles of thermodynamics through historical facts and everyday experiences, which relate to energy and energy transformation of heat into other forms of energy and vice versa.

Objective 2. Introduce pure substances through phase change processes in order to establish the relationships among thermodynamics properties and to discuss the results of those measurements and calculations in thermodynamics property tables.

Objective 3. Introduce the first law of thermodynamics with the Conservation of Energy Principles and their application in both closed and open systems.

Objective 4. Introduce the second law of thermodynamics with the Concept of Entropy and Degradation of Energy during energy transfer in order to determine the theoretical limits for the performance of commonly used engineering systems.

Concept Map Structure

The course concept map was developed using the above topics and objectives as a foundation. However, to structure the map, we refrained from examining the details of this course and asked the question: How do the course concepts "fit" into the solution procedure previously discussed? Secondly, the first question was asked in reverse: How does the presented solution formulation methodology "fit" with the course topics/objectives. Asking these questions produced three major results in terms of looking at the subject matter holistically. The ***first result*** reveals that each **thermodynamics problem usually requires knowledge of the working substance's phase**. Phase knowledge is very important in understanding a substance's behavior. The ***second result*** of this inquiry is that the physical state of a **thermodynamic system is described by a finite number of intensive and extensive properties (or variables)**. A thermodynamics system is defined as a quantity of matter or a region in a space chosen for study, and a property (i.e., temperature, pressure, etc.) is defined as any characteristic of that system.[1, 4] The ***third result*** from the inquiry reveals that the **behavior of the working substances is governed by one or more equations**. For example, the Ideal Gas Law, as noted in the Introduction section of this paper, can be shown to model (or govern) the behavior of many gases under the proper conditions. This law states that pressure and specific volume are inversely proportional to each other, but both of these variables are directly proportional to temperature. It also tells us that for a fixed mass system the Pv to T ratio of such a substance is constant from state to state. Its governing equation is given as,

$$Pv = RT \tag{1}$$

where, R is the gas constant of the gas. A graphical depiction of this relationship is illustrated in Figure 2.

Other governing equations or relations for typical thermodynamic substances include, the ideal gas law with compressibility, other equations of state (van der Waals, Beattie-Bridgeman, etc.) pressure equations, work-energy equations, steam property data (usually in tabular form), and efficiency and entropy relations. To the student, when one takes the observations from all of these three areas into consideration, it can be intimidating because each of the three areas has a number of selections. Ideally, the student sees all of the terms, variables, and equations, and realizes that they relate in some way to the solution of the problem; but this is not always the case.

To overcome this challenge, the elements of the three areas have been laid out graphically using three-dimensional pie charts, as shown in Figure 3. Hence, the student can visualize the individual components of the major areas and how they relate to the whole problem. Secondly, the student is made aware that at least one item from each chart is usually required for the solution of many problems. In some cases, several model items (e.g., governing equations) must be selected to solve a problem. So, the course concept map consists of the three pie charts shown in Figure 3. The three charts are entitled, Phases, State Properties, and Models.

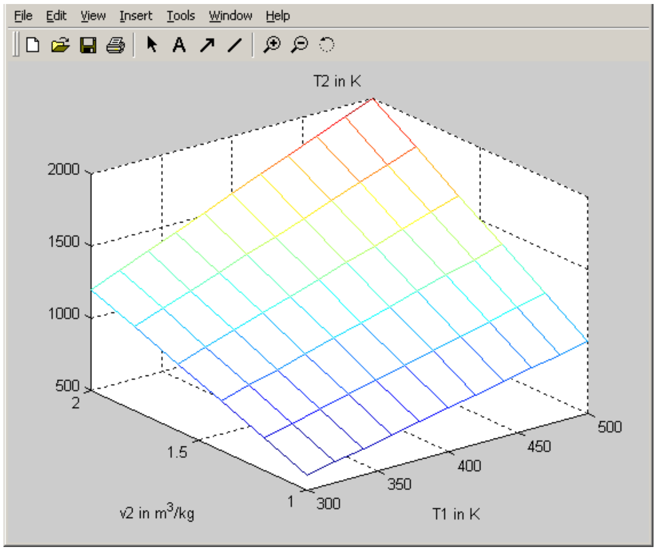
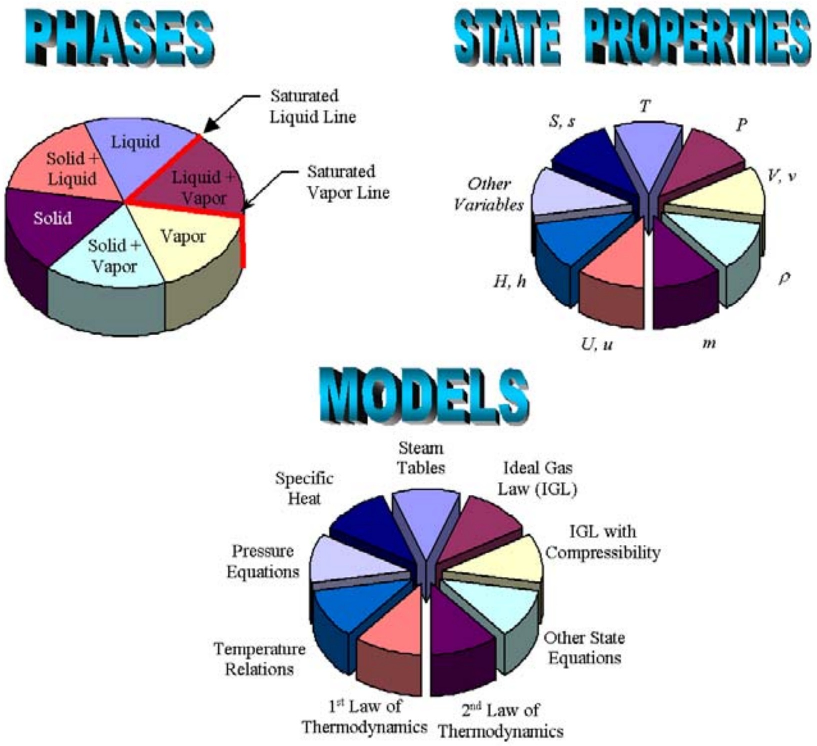


Figure 2. A graphical representation of the final temperature (T_2) surface for an ideal gas with an initial specific volume (v_1) of 1 m^3/kg, initial pressure (P_2) of 100 kPa, and a final pressure (P_2) of 200 kPa. The other two terms, the final specific volume (v_2) and initial temperature (T_1) are allowed to vary over the range of values shown on the graph. The graph was produced using the open architecture Ideal Gas Graphics System (IGGS).[5, 6]



Legend

T = Temperature
P = Pressure
V = Volume
v = Specific Volume
ρ = Density
m = Mass
U = Internal Energy
u = Specific Internal Energy
H = Enthalpy
h = Specific Enthalpy
S = Entropy
s = Specific Entropy

Figure 3. Concept Map for a Thermodynamic Substance

The Phases pie chart shows the different states of matter with the exclusion of plasma, which is a state normally not handled in this course. These states are solid, liquid, and vapor (or gas). The pie chart is also well suited to illustrate the two-phase characteristics, which exist frequently in thermodynamic analysis, such as, the liquid and vapor mixture. It should also be noted that the edges of the slices of the Phases chart "touch" the adjacent slices. This subtly shows that phase transformation is usually a continuous process, with the exception of the sublimation process. For example, a substance in a liquid phase must go through the two-phase (liquid + vapor region) before all of it can be converted to the vapor phase. Because of their frequent uses, the locations of the saturated liquid and saturated vapor lines have also been denoted on the diagram.

The State Properties chart is configured so that each pie slice represents an intensive or extensive property. These types of properties are all put on the pie without making any differentiation between them. This is because they all must be used in unison when solving problems. The legend on the right side of Figure 3 provides the property name for each symbol used in the chart. Several properties have been associated with the same pie slice because of their inherent similarities, such as enthalpy and specific enthalpy, and entropy and specific entropy.

The Models pie chart provides the names of the governing equations (relations) that are typically used in this course. These relations predict the behavior of the state properties from one state to the next. In other words, they act as the glue that tie the properties and phase(s) together. Each relation is associated with one slice of the pie. The names of these relations are also listed in Table I, along with their accompanying equation(s).

Example of Concept Map Utilization

To illustrate the usefulness of the presented concept map, a word problem will be posed and a solution will be generated. In the initial solution formulation process, the relevant terms that are on the concept map will be identified. Another pie chart will be constructed which will represent the border of a puzzle. This new puzzle (Solution Chart) is then completed by using the elements of the concept map to fill in the missing "slices" (components) of the puzzle. As the puzzle is completed, two things will be clearly seen, (1) the governing equations necessary to solve the problem will be evident, and (2) knowledge of the constraints of the problem will be evident.

Problem: The refrigerant R-134a enters a compressor at a rate of 2.5 kg/s as a saturated vapor at -12°C and leaves at 600 kPa and 50°C. If the power input to the compressor is 130 kW, what is the rate of heat lost during this process?

Given:
System substance: refrigerant R-134a
Compressor inlet temperature: T_{in} = -12°C (saturated vapor)
Compressor outlet temperature: $T_{out} = 50°C$
Compressor outlet pressure: $P_{out} = 600$ kPa
Mass flow rate of substance: $\dot{m} = 2.5$ kg/s
Compressor input power: $\dot{W} = 130$ kW

Find: Heat lost during the process: $\dot{Q}_{loss} = \dot{Q}_{out} = ?$

Solution Formulation:

Phases: Based on the problem statement, it is known that the R-134a is at a **saturated vapor** state at the system inlet. So, from the given T_{in} data the other state property data (pressure, enthalpy, specific volume, etc.) can be found from R-134a property tables (which are similar to the steam tables). Using the given T_{out} and P_{out} values, the tables show that the R-134a exits the system as a **superheated vapor**.

State Properties: From the R-134a table it is found that

Inlet pressure: $P_{in} = 185.4$ kPa
Inlet enthalpy: $h_{in} = 240.15$ kJ/kg
Outlet enthalpy: $h_{out} = 288.33$ kJ/kg

Other properties may be obtained, but the above should suffice for this problem.

Models: Since the compressor has only one inlet and one exit, it will be modeled using a control volume undergoing steady flow process. Also, after examining the givens and the equations from Table I, it is found that the rate form energy balance equation (EBE) from the first law of thermodynamics can be directly used to compute the heat loss, $\dot{Q}_{out}$. For compressors, the potential and kinetic energy changes are normally negligible relative to enthalpy changes. And finally, for a steady flow process, there is no system energy or mass change with respect to time. These relations are given below.

Rate form of EBE: $$\dot{E}_{in} - \dot{E}_{out} = \dot{E}_{system} \qquad (1)$$

where, $$\Delta E_{system} = \Delta U + \Delta KE + \Delta PE = 0$$

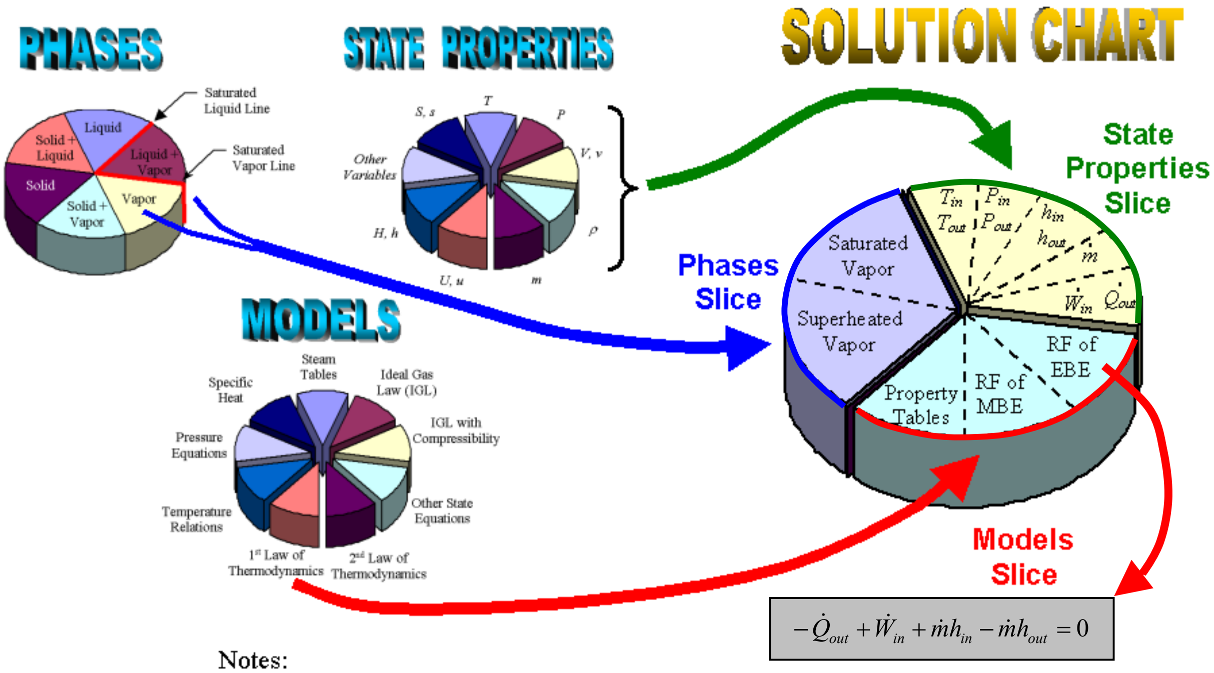
and $$\dot{E}_{in} - \dot{E}_{out} = \underbrace{\dot{Q}_{in}}_{0} - \dot{Q}_{out} + \dot{W}_{in} - \underbrace{\dot{W}_{out}}_{0} + \underbrace{\dot{E}_{mass,in}}_{\dot{m}h_{in}} - \underbrace{\dot{E}_{mass,out}}_{\dot{m}h_{out}}$$

Therefore, final form of the solution's governing equation is

$$-\dot{Q}_{out} + \dot{W}_{in} + \dot{m}h_{in} - \dot{m}h_{out} = 0 \qquad (2)$$

and the heat loss can be directly computed from it.

Figure 4 graphically shows how each of the three elements ties into the Solution Chart. So, from the concept mapping the student would be able to clearly see the phases, state properties, and model(s) required to solve this problem. The final solution execution stage is the only thing that remains. Solving the for the $\dot{Q}_{out}$ value, the only unknown in Eq. (2), produces a heat transfer (loss) value of 9.55 kW which is slightly more than 7% of the input power.



Notes:

RF of MBE means rate form of the mass balance equation
RF of EBE means rate form of the energy balance equation

Figure 4. Implementation of Concept Map for the Solution of Posed Compressor Problem

Course Implementation of Maps

The presented concept map is scheduled to be implemented in the MEEN 300 course during the Spring 2003 semester. As a pre-implementation exercise the students will first be required to first read several articles on concept mapping.[7, 8, 9, 10] These articles will provide a basic overview and rationale behind concept mapping. Secondly, they will also be required to read this paper. In conjunction with the second step, a presentation will be given to the students to formally discuss the map as it relates to the goals and objectives of the Thermodynamics I subject. Several problems will also be presented where the elements of the map are utilized to formulate a solution (i.e., creation of a Solution Chart as shown in Figure 4). Finally, the students will be required to independently solve the problems for homework, where they will draw and indicate the elements used from the map to produce a Solution Chart. Results of this implementation will be disseminated through publication and conference proceedings.

Model Name	Equation(s) or Relation
Pressure Equations:	
- Pressure, force, and area	$P = F/A$
- Gage and vacuum pressure	$P_{gage} = P_{abs} - P_{atm}$ and $P_{vac} = P_{atm} - P_{abs}$
- Pressure differential	$\Delta P = P_2 - P_1 = \rho g \Delta z$
Temperature Relations:	
- Celsius to Kelvin conversion	$T(K) = T(°C) + 273.15$
- Fahrenheit to Rankine conversion	$T(R) = T(°F) + 459.67$
- Differential temperature conversions	$\Delta T(R) = \Delta T(°F)$ and $\Delta T(K) = \Delta T(°C)$
Steam (and Other Substance) Tables:	
- Tabular property data	Data includes specific volume, internal energy, enthalpy, and entropy at a specified temperature and pressure for water (liquid, vapor, and saturated) and other substances, such as typical refrigerants.
- Quality	$x = m_{vapor}/m_{total}$
Ideal Gas Law (IGL):	$Pv = RT$
IGL with Compressibility:	$Z = \frac{Pv}{RT}$ or $Z = \frac{v_{actual}}{v_{ideal}}$ the *Z* term should be used in conjunction the Nelson-Obert Generalized Compressibility charts along with the reduced pressure, P_r, reduced temperature, T_r, and pseudo reduced specific volume, v_r, terms.[1]
Other State Equations:	
- van der Waals	$(P + a/v^2)(v - b) = RT$ where, $a = 27R^2T_{cr}^2/(64P_{cr})$ and $b = RT_{cr}/(8P_{cr})$
- Beattie-Bridgeman	$P = (R_uT/\bar{v}^2)[1 - c/(\bar{v}T^3)](\bar{v} + B) - a/\bar{v}^2$ where, $A = A_o(1 - a/\bar{v})$ and $B = B_o(1 - b/\bar{v})$ R_u is the universal gas constant and $\bar{v}$ is the specific volume on a molar basis.
Specific Heat, Internal Energy, and Enthalpy:	
- Constant volume specific heat	$C_v = (\partial u/\partial T)_v$ and $\Delta u = u_2 - u_1 = \int_1^2 C_v(T)dT$
- Constant pressure specific heat	$C_p = (\partial h/\partial T)_p$ and $\Delta h = h_2 - h_1 = \int_1^2 C_p(T)dT$
- Specific heat ratio	$k = C_p/C_v$
1st Law of Thermodynamics:	
- Energy balance equation (EBE)	$E_{in} - E_{out} = \Delta E_{system} = E_{final} - E_{initial}$ where, $E_{in} - E_{out} = (Q_{in} - Q_{out}) + (W_{in} - W_{out}) + (E_{mass,in} - E_{mass,out})$ and $\Delta E_{system} = \Delta U + \Delta KE + \Delta PE$
- Rate form of EBE	$\dot{E}_{in} - \dot{E}_{out} = \Delta \dot{E}$
- Mass balance equation (MBE)	$\sum m_{in} - \sum m_{out} = \Delta m_{system}$
- Rate form of MBE	$\sum \dot{m}_{in} - \sum \dot{m}_{out} = \Delta \dot{m}_{system}$

Table I. Relational Elements of the Models Pie Chart.

Model Name	Equation(s) or Relation
2^{nd} Law of Thermodynamics Application:	
• Thermal efficiency (Heat Engine)	$\eta_{th} = W_{net,out}/Q_H = 1 - Q_L/Q_H$
• Thermal efficiency (Carnot Heat Engine)	$\eta_{th,rev} = 1 - T_L/T_H$
• Coefficient of Performance (refrigerator)	$\mathrm{COP}_R = Q_L/W_{net,in} = (Q_L/Q_H - 1)^{-1}$
• Coefficient of Performance (reversible refrigerator)	$\mathrm{COP}_{R,rev} = (T_H/T_L - 1)^{-1}$
• Entropy definition (internal reversible process)	$\Delta S = Q/T_o$
• Entropy change (pure substance)	$\Delta s = s_2 - s_1$
• Entropy change (incompressible substance)	$s_2 - s_1 = C_{av} \ln(T_2/T_1)$
• Entropy change (ideal gas) assuming constant specific heats (approximate)	$s_2 - s_1 = C_{v,av} \ln(T_2/T_1) + R \ln(v_2/v_1)$
• Entropy balance	$S_{in} - S_{out} + S_{gen} = \Delta S_{system}$
• Rate form of entropy balance	$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \Delta\dot{S}_{system}$

Table I (continued). Relational Elements of the Models Pie Chart

Conclusion

Concept maps can be developed to create or illustrate complex structures, to communicate complex ideas in different ways, to aid learning allowing one to see relationships, contradictions, and gaps in the material, and to encourage creativity and discovery.[7,8] A concept map for the Thermodynamics I course taught a Southern University has been presented. This engineering course primarily focuses on understanding thermodynamics systems and solving problems related to those systems. To solve engineering problems, the student must recognize and assemble relevant data, concepts, terms, and relations. This map attempts to give the student a holistic view of the course's subject matter. It inherently combines the subject matter and a systematic problem solving technique to enable the student to fill in the blanks for a solution. This paper also provides an example to demonstrate how the map can be utilized to solve a thermodynamics problem. Because of the design and structure of this map, it is hoped that the student will be able to qualitatively and quantitatively grasp the linkages between the fundamental concepts presented in the course, as well as appropriately apply them in the analysis of engineering systems.

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