AC 2010-1510: CONCEPT BASED LEARNING: DEMONSTRATING ITS EFFECTIVENESS IN THERMODYNAMICS

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Concept Based Learning:

Demonstrating its Effectiveness in Thermodynamics

1. Project Overview

Features:
This project examines the coupling of concept based learning and findings from the fields of neurology and cognitive science to empower students to solve problems of increasing complexity. The central question the authors seek to answer is: does concept based learning offer an advantage to students in terms of their ability to learn to solve both traditional and never before seen problems? A sophomore level thermodynamics class is used in this study to test the effectiveness of concept based learning. The project's goal is to investigate concept based learning as an effective means of delivering material to students in ways that acknowledge and capitalize upon the physiological process of learning.

Objectives:
The objectives of this project are to:

- Build a thermodynamics course based on conceptual understanding rather than the traditional topic by topic approach.
- Develop educational activities and tools that capitalize on the physiological process of learning through the use of concept based teaching and learning.
- Provide resources for students that will help identify weaknesses in conceptual understanding and that will help them overcome these weaknesses.
- Understand how concept based learning and teaching can be used to improve methods for quantification of learning.

Process:
Investigators will first outline a teaching methodology which they believe, through both practice and the findings of cognitive scientists, to be more effective than that traditionally used in engineering education (i.e., that of an algorithmic approach toward the solution of problems and rote memorization). Student feedback and performance on certain activities will be used to improve the course. As the methodology for implementing concept based pedagogy is refined, activities and tools consistent with the methodology will be developed. These activities and tools will utilize known effective methods for optimizing the physiological process of learning.

Why concept based teaching is needed:

- Wicked" problems, as they have been called, are interdisciplinary, multi-cultural, and seemingly intractable. By definition, wicked problems are novel. Such problems include global climate change and ensuring the availability of clean water and sustainable energy to a burgeoning world population. For the most part, current practices in engineering education prepare students to solve similar problems to those that they have encountered in their textbooks and by their predecessors, i.e., "tame problems"[1]. "Wicked problems" cannot be solved conventionally and it is not likely that conventional training will mitigate them. While it is clear that there is a need to grow the numbers of scientists and engineers required to take on the challenge of these types of problems [2], the idea of reforming the way in which they are trained has gained little traction. Recent advances in technology have enabled neurologists and cognitive scientists to map brain activity and describe ways in which people best learn and retain information. Scientists know that for learning to occur, neural pathways must be formed. New neural paths begin with existing memories and these pathways, to remain viable, must be repeatedly used [3].

- Concept based teaching intrinsically lends itself to providing integrated course design. The key components of integrated course design are learning goals, teaching and learning activities, feedback, and assessment [4]. This project proposes learning activities designed to reinforce a fundamental set of thermodynamic concepts. With repeated use of these concepts, coupled with timely feedback, learning is better facilitated because it is integrated and leverages known physiological phenomena. Each concept is developed within the course and students are given activities that require them to struggle with their understanding of the concept. Students pull several of these concepts together to solve thermodynamics problems. The material is introduced in a fashion that enables students, regardless of background (ethnicity, gender, cultural background, etc.) to develop conceptual understanding. This feature of concept based learning, superimposed difficulty to the point of struggle, enables students to successfully take the first step required in learning.

- Concept based learning capitalizes on what is now empirically confirmed: meta-cognition, connection to past memories, and recurring use of nascent neural pathways results in increased understanding and retention of information [5]. Unawareness of these findings upholds continued educational practices that fail to capitalize on what is known to initiate learning. The critical first step in promoting learning is to acknowledge that learning begins with pre-existing knowledge. Prior knowledge is formed through life experience: gender, socio-economic status, culture, ethnicity, and numerous other characteristics and circumstances fashion a person's collective knowledge [6]. It is imperative to identify and build on pre-existing knowledge with the diversity of a student population in mind because it increases the chance for a student to connect his or her past memories to new information, which is learning. Knowing what facts, skills, related topics, or generalizations that students have previously committed to memory equips the educator in helping students bridge past memories to new ones; it is this process that characterizes concept-based learning. "Enduring, essential understandings" result [7] when a concept based approach is used to teach and learn. Conceptual understanding energizes the process of these enduring and essential understandings by making transfer across disciplines possible. Knowledge, understanding and skill [8] constitute robustness in learning that the transfer of knowledge alone does not possess. It is in the *understanding* of that knowledge that concept based learning offers its greatest advantages.

2. Concept Based Learning: Sample Instructor's Guide

The practice of concept based learning requires the instructor to break a course down into key concepts. Once these key concepts are identified, the course material must be redeveloped. All new material is developed based on existing concepts. When new concepts are needed, the concepts are introduced (via 5-10 minute concept videos in this thermodynamics course) and examined through in-class activities. The specific goal of this teaching style is to develop understanding of the material that will allow students to solve any problem in the thermodynamics book without an equation sheet or any other materials, i.e., to solve the problem based on a deep understanding of the material. With deep understanding sufficient to solve any problem in a thermodynamics text as an end goal, it becomes apparent quickly when students do not understand concepts or if they lack the skills necessary to demonstrate understanding of concepts. This information gives the instructor specific things to change in the course. The process of simplifying class material into pieces that are used throughout the entire class and the process of revising classroom activities provides students with an improved course every semester. Over many course iterations, the improvement in student understanding is dramatic. This is specifically testable by measuring the ability of students to solve new problems that they have never before seen.

Using concept based learning methods, the instructor learns how to provide activities that overcome common mistakes made by students (If many students are making the same mistake, it is likely an instructional problem).

Some common mistakes in thermodynamics:

1) **Using the wrong equation or using an equation under inappropriate conditions.**
   Reason – students are presented with hundreds of equations in their textbook. Typically the new forms of the equations are presented *as needed* for a specific topic without enough emphasis on the assumptions of the equation. The sheer number of equations makes student understanding very difficult.
   Solution – help students to learn a few general equations (based on key concepts) that can be used throughout the course. Assumptions for a given problem can be introduced into the general equation to obtain the correct specific equation. Do not give students any equations on exams--this will make understanding of the development of the key equations a requirement for success in the course.
2) **Sign error**
   Reason - This is the most common mistake in mathematics. The traditional approach for thermodynamics (Q, *heat*, is in and W, *work*, is out) does nothing to prevent sign errors.
   Solution – Provide all of the equations as a balance for the control volume. Property In – Property Out = Change in Property. Have students determine how energy by heat transfer and work (or how any other property such as mass or entropy) enter or leave the control volume prior to solving the problem, and insert each term as an in or out term in the balance equation. This requires the additional

understanding of whether heat and work are in or out for a given problem. This completely eliminates negative numbers and if students obtain a negative number in the solution, they are likely to go back and find their mistake (because they know their final answer is wrong).

3) **Unrealistic Answers**

   Reason – This can be attributed to a basic lack of understanding of what is happening in a given problem as well as not requiring students to figure out if their answers are reasonable.

   Solution – The concept based learning method will help because it results in improved understanding. Eliminating errors in equation development and sign errors will also help. Students of a concept based learning method will be able to identify incorrect answers as well as the specific step causing trouble.

The following sample instructor's guide demonstrates a method of teaching which combines concept based learning strategies with techniques that promote the physiological process of learning. The instruction guide demonstrates how a refrigeration cycle works based only on the knowledge of what happens when a gas is expanded or compressed. If the three concepts in this activity are understood, students should be able to explain what happens to pressure and temperature for the four components of a refrigeration cycle based on this conceptual understanding.

Instructor's note: In this thermodynamics class students learn to solve air problems for open, closed, and slowly leaking or filling containers before learning about fluids undergoing phase changes. Introducing open and closed systems at the same time helps to eliminate confusion between the two, as does repeated use of both open and closed systems throughout the course. For a 15 week course, the exams are divided up as follows:

Exam	**Week**	**Material Covered**
1	5	Air problems for open, closed, and slowly leaking or filling containers.
2	9	Water or refrigerant problems for open, closed, and slowly leaking or filling containers.
3	13	Entropy production for any fluid for open or closed systems
Final	15	Comprehensive plus complex Rankine power cycles

The following learning activity on refrigeration cycles would be introduced around week 3 of a 15 week course as part of Exam 1 material, which is much earlier than can be done using traditional methods. The refrigeration cycle would be presented again as part of Exam 2 material with the addition of phase changes for a refrigerant in the heat exchangers. The refrigeration cycle can be presented again as part of Exam 3 material to determine how good a specific refrigeration cycle performs. In a traditional thermodynamics course, refrigeration cycles would be explained either very late in the course, or even in a subsequent thermodynamics course. With the concept based approach, cycles can be emphasized and understood early in the course.

Learning Outcome: to utilize fundamental thermodynamic concepts to create and further understanding of a refrigeration cycle

- What happens to temperature and pressure when a gas is compressed?
- What happens to temperature and pressure when a gas is expanded?
- Heat transfers from a hotter object to a colder object.

Prior Concepts Needed

a) To compress a gas, the gas will be "pushed", adding energy to the gas by work
b) If allowed, a gas will expand from high pressure to low pressure, removing energy from the gas by work

KEY CONCEPT 1: What happens to temperature and pressure when a gas is compressed?

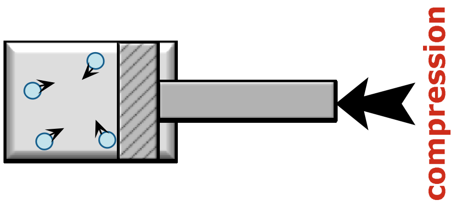

Figure 1 (a): Energy Being Added

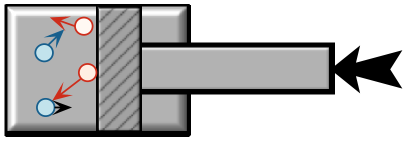

Figure 1 (b): Increased velocity of molecules

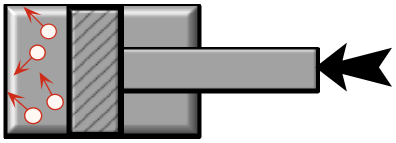

Figure 2: Increased velocity of molecules increases gas temperature

In Figure 1(a), individual ***low velocity*** molecules are shown in blue. These molecules bounce around inside the piston chamber, colliding with each other, the walls of the cylinder, and with the piston. The direction and speed of each molecule is represented with an arrow. As the molecules collide with the piston, the compressive force pushing the piston to the left will add energy to the molecule. The molecules striking the moving piston will rebound with higher velocities due to the energy added by the compression of the piston, as indicated by the increased length of the velocity vectors in Figure 1(b). In Figure 2, high velocity molecules impart more energy which results in an increased temperature of the gas.

During compression the temperature of a gas increases.

Pressure is force per unit of area. The molecules in the smaller (compressed) volume will collide more often with the walls and the piston, producing a larger force per area, and as a result, increased pressure.

During compression, the pressure of a gas increases.

KEY CONCEPT 2: What happens to temperature and pressure when a gas is expanded?

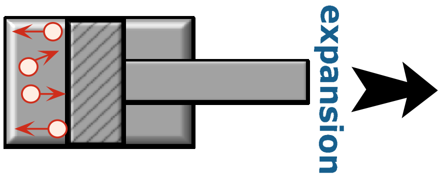

Figure 3(a): Molecules "pushing" piston

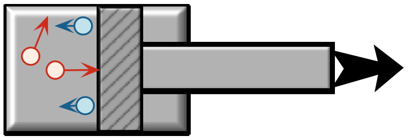

Figure 3(b) : Decreased velocity of molecules in expansion

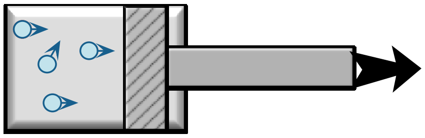

Figure 4: Decreased velocity of molecules decreases the gas temperature

During an expansion, the force of the high velocity (red) molecules is larger than the force that holds the piston in place. As molecules (Figure 3(a)) hit the piston, the resulting force will cause the piston to move to the right or, to expand. Some of each molecule's energy is used to push the piston to the right. Molecules striking the piston during an expansion will have a lower velocity as they transfer energy to the piston. The molecule striking the piston rebounds with *decreased* velocity, which is shown as a shorter velocity vector in Figure 3(b), due to the energy transferred from the molecule to the piston. As the piston continues to expand, molecules will have decreased velocities. Molecules with a lower velocity have less energy which corresponds to a decreased temperature of the gas as indicated in Figure 4.

KEY CONCEPT 1: During expansion, the temperature of a gas decreases.

Pressure is force per area. For the larger (expanded) cylinder volume, the molecules will collide less frequently with the walls and the piston, resulting in smaller force per area.

KEY CONCEPT 2: During expansion, the pressure of a gas decreases.

KEY CONCEPT 3: Heat transfer goes from hot to cold.

- For a gas, higher temperature molecules will have a higher velocity.
- For a gas, lower temperature molecules will have a lower velocity.

Consider the case represented in Figure 5, a container divided in half with high temperature gas molecules on the right side and low temperature gas molecules on the left side. The pressure is the same throughout the container. If there were the same number of particles on each side of the container, the high temperature (and high velocity) particles would exert a larger force on the container, which would mean that the pressure would be higher on the right hand side of the container. Based on what has been learned about pressure, there will have to be fewer high temperature particles on the right hand side of the container for both sides of the container to have the same pressure.

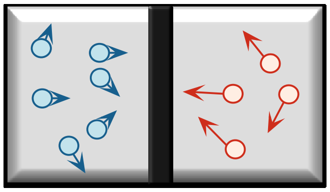

Figure 5: High and low velocity molecules

After the divider is removed, high velocity particles collide with lower velocity particles and some of the energy of the high velocity particles is transferred to the low velocity particles. After many collisions, most of the particles in the container will have a velocity somewhere between the initial high and initial low velocities, as shown in Figure 6. The molecules on the left hand side of the container now have higher velocities indicating that they also have more energy (a higher temperature). This is how heat is transferred from the hot side of the container to the cold side of the container for a gas. For solids and liquids, molecules can also store and pass on energy in ways other than through velocity. The result is the same. Higher energy (*higher temperature*) particles will tend to transfer energy to lower energy (*lower temperature*) particles.

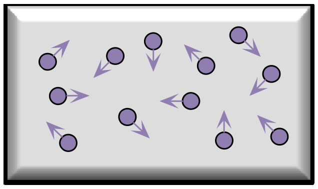

Figure 6: Molecules reach velocities between the highest and lowest initial velocities

KEY CONCEPT 3: Heat transfer goes from hot to cold.

KEY CONCEPTS

- Temperature and pressure increase when a gas is compressed
- Temperature and pressure decrease when a gas is expanded.
- Heat transfer goes from a hotter object to a colder object

Application of Concepts

Consider a hypothetical window air conditioner that keeps a single room cool at 72^{o}F while the outside temperature is 85^{o}F. Nitrogen gas repeatedly runs through the components of the air conditioner to keep the room cool. The air conditioner works by *transferring heat out of the room* and *into the nitrogen* that is inside the air conditioner. Let’s say that the window air conditioner turns on when the room reaches a temperature of 72^{o}F and sends out cool air at 65^{o}F.

Based on our understanding of heat transfer from hot room air to cold nitrogen, the nitrogen gas refrigerant will have to be colder than 65°F when it enters the heat exchanger. The first component of the refrigeration cycle is a heat exchanger that is used to transfer heat from the room to the refrigerant. As shown in Figure 7, air enters the heat exchanger at 72°F and is cooled to 65°F. The nitrogen in the air conditioner enters the heat exchanger at 60°F and exits at 67°F as heat is transferred from the hot air to the cooler nitrogen.

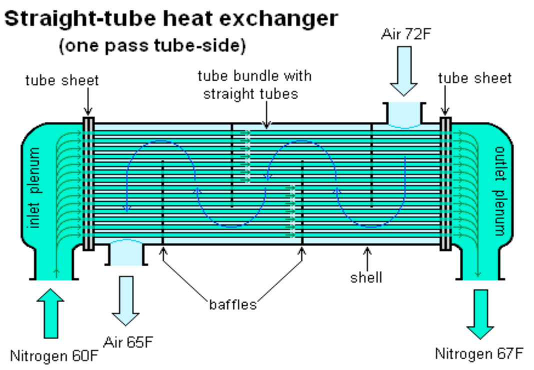

Figure 7: Low temperature heat exchanger

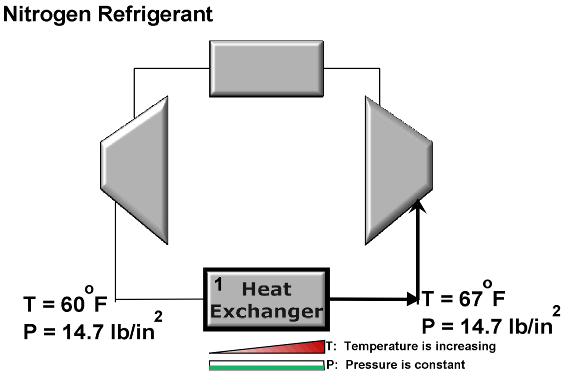

Figure 8: Component 1, low temperature heat exchanger

COMPONENT 1: Heat exchanger transfers heat from the air in the room to the nitrogen refrigerant, cooling the air conditioned room.

The energy that was added to the refrigerant in the heat exchanger must now be removed to the outside air at 85°F. For this to happen, the nitrogen refrigerant will need to be hotter than 85°F. The second component of the refrigeration cycle will need to raise the temperature of the nitrogen exiting the heat exchanger from 67°F to above 85°F. We know that if we compress the nitrogen gas, both its temperature and pressure will increase. The second component of the refrigeration cycle is a compressor. High pressure (20 psi) and high temperature (97°F) nitrogen will exit the compressor.

Compressor Inlet

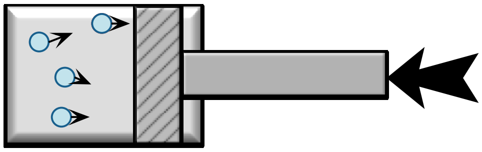

Figure 7(a): Nitrogen, 67°F, low pressure

Compressor Outlet

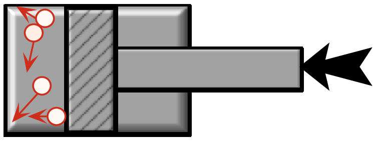

Figure 9(b). Nitrogen, 97°F, high pressure

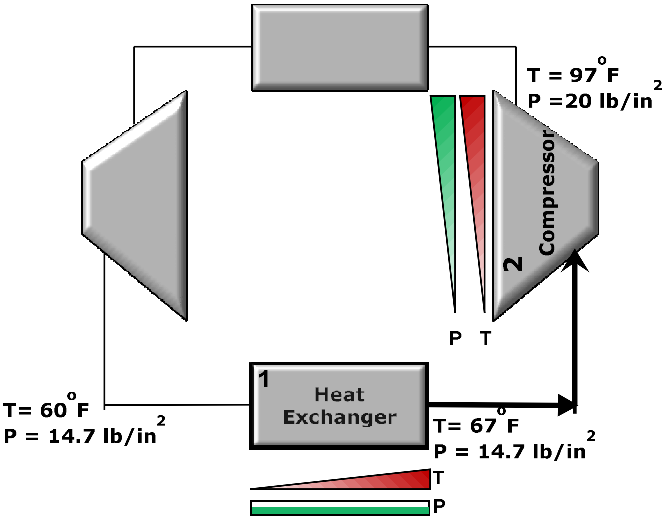

Figure 8: Component 2, compressor

COMPONENT 2: Compressor raises the temperature and pressure of the refrigerant

The third component of the refrigeration cycle is another heat exchanger that transfers heat from the high temperature (97°F), high pressure (20 psi) nitrogen gas to the outside air at 85°F. In the above example, the nitrogen refrigerant enters at 97°F and cools to 90°F. The outside air enters at 85°F and heats up to 92°F as it receives energy from the hotter nitrogen refrigerant. Typically, a fan blows outside air past the hot refrigerant in this heat exchanger. The air on the outside of a running window air conditioner is hot because air blows past the heat exchanger. Figure 11 is a schematic of the heat exchanger and Figure 12 includes the high temperature heat exchanger.

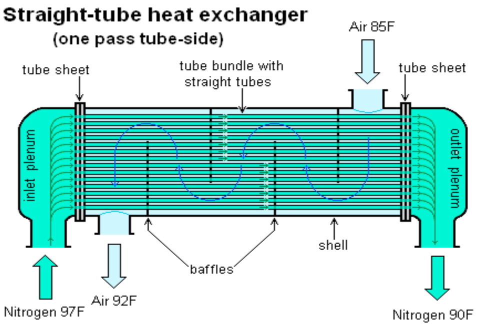

Figure 9: High temperature heat exchanger

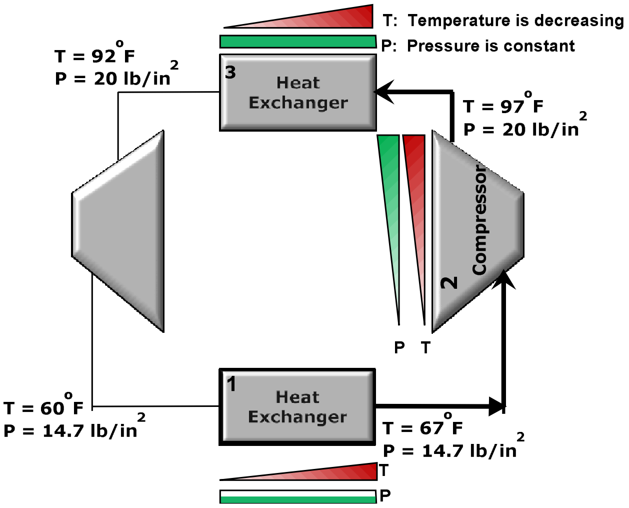

Figure 12: Component 3, high temperature heat exchanger

COMPONENT 3: Heat exchanger transfers heat from the hot nitrogen to the outside air

The last component of the cycle needs to lower the temperature of the nitrogen gas back to 60°F to complete the cycle. If we expand the nitrogen gas exiting from the high temperature heat exchanger, the temperature will drop from 92°F to 60°F and the pressure will drop from 20 psi to 14.7 psi.

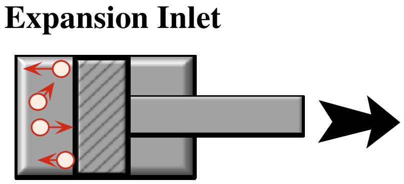

Figure 13(a): Nitrogen, 92°F, high pressure

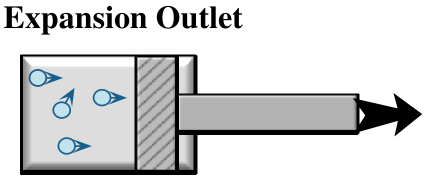

Figure 13(b). Nitrogen, 60°F, low pressure

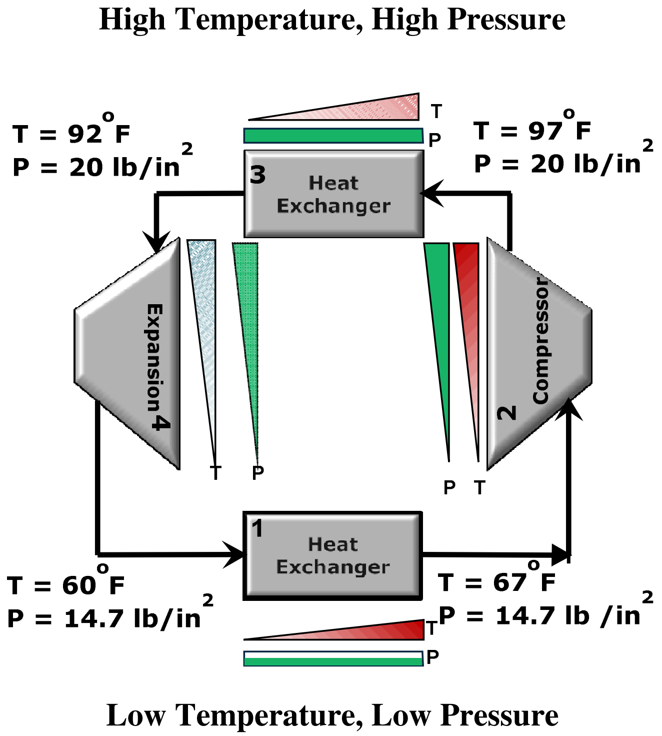

Figure 14: Component 4, Expansion

COMPONENT 4: Expansion lowers the temperature and pressure of the refrigerant

3. Leveraging Cognitive Science

In the preceding instructor's guide the following features are prevalent and take advantage of the physiological process of learning:

- Learning outcomes are non-specific and dependent on existing memories.
- Specific prior memories critical to new concepts are explicitly stated.
- Learning outcomes are relevant to students.
- Short phrases summarize new concepts.
- Application of new concepts requires retrieval of short and long term memories.

The significance of each of these features is supported with well established findings in the cognitive and behavioral sciences and more recently supported with advancements in brain imaging and neuroscience.

Learning outcomes are non-specific and dependent on existing memories

Setting specific problem solving goals encourages students to strategize on ways in which to "get the answer" while non-specific problem solving goals encourages them to learn why the answer is what it is. Furthermore, cognitive load is reduced when problem solving goals are non-specific enabling students to learn with less effort. [9] [10] [11].

Existing memories are necessary for learning to occur [12]. Neurons fire when activated through questioning or challenge that requires recall or "connection" to past memories. New neural pathways are established using chemical and electrical processes collectively referred to as "synaptic transmission" [13]. Synaptic transmission begins with existing memories and is the process by which new memories are created. Without the possibility of "connecting" to a past memory learning will not occur.

Specific prior memories critical to new concepts are stated

This phenomenon of strengthening synaptic connections between neurons was first postulated by Donald Hebb and is frequently summarized as "neurons that fire together wire together". As noted in *How Students Learn,* students are not always aware that the knowledge they possess is relevant. However it is the perceived relevancy of knowledge that enables people to organize information in ways that allows them to better retain it [14]. Consequently, it is important for instructors to be clear and explicit in identifying relevant past information.

Learning outcomes are relevant to students

Immordino-Yang and Damasio [15] point out that present day brain evolution bears evidence of its original purposes: to ensure self preservation. Visual, auditory, kinesthetic, olfactory, and gustatory signals are first processed through the most primitive part of the brain—the cerebellum. This information is directed to the limbic system where decision making and emotions reside. It is at this point that the student will determine whether or not the information he or she is receiving warrants storing in memory. The most advanced portion of the brain, the neocortex, enables higher order thinking that includes the consideration of the consequences of decisions. In a traditional class, many students do not have the level of expertise required to accurately gage the relevancy of new information. Contrastingly, concept based learning environments require students to use new information immediately and frequently throughout the class.

Short phrases which summarize new concepts

More than 50 years ago [16] cognitive psychologists observed that the human capacity for storing information to short term memory was "seven plus-or-minus two" *chunks* of information. For single syllable words, effective chunking appears to drop off to approximately five chunks. The phenomena of effectively committing information to short term memory by chunking bits of information is supported with research that spans the 50 years since the phenomena was first postulated [17, 18]. The ultimate goal of education is to transfer information from educator to student that will be retained in the student's long term memory and applied as required by circumstances. Recent research has shown that chunking can be related to the long term memory skills required to increase expertise in highly cognitive activities [19]. The use of short, high information phrases, particularly with phrases which include new terms and/or nomenclature, gives the student the advantage of "chunking" information.

Retrieval and application of new concepts

Neurobiologists have understood for some time that as learning occurs, physiological changes occur in the brain which results in neurons making new connections to one another. The role that repetition plays in the establishment and strengthening of these new paths is critical [20, 21]. Repetitive and timely use of recently formed neural pathways is critical for successful commitment of new information to long term memory. (It should be noted that for the same reason, timely feedback to students on their understanding of new concepts is critical as wrong information is as easily stored in long term memory as correct information). Timely and appropriate application of new concepts is also a means of reinforcing the relevance of new information to students.

4. Concept Based Learning and Quantification of Learning

Theories abound for ways of measuring learning. Fundamentally, learning is about contrasts: contrasts at points in time regarding knowledge, understanding, and skill that is transferred from the instructor to the student. The transference of information alone does not constitute learning in its full measure, although this mode of learning is easily quantifiable (exams for example). A higher mode of learning is using facts to arrive at understanding. To quantify understanding it is necessary to frame the instrument of measure in the context of the central concept(s); Erickson calls this a "conceptual lens" [22]. For example, after learning the facts about expansion and compression, the concept of heat transfer becomes more apparent. A student who *understands* the concept of heat transfer would be able to explain why a can of compressed air becomes cold when the air in the can is released. The highest mode of learning is in applying both facts and understanding which results in the demonstration of skills through application; this type of learning can be measured by assigning synthesis tasks, i.e., design a rudimentary refrigerator and optimize its performance. While the quantification methods proposed here are straightforward, considerable changes to the delivery of course content are to be expected.

5. Results

The concept based learning method as implemented in thermodynamics is very successful, in that students can solve thermodynamics problems based on deep understanding rather than through the use of rote memorization and similar reference problems. Other studies centered on a concept based approach in teaching thermodynamics confirm this claim [23]. While readers may desire a direct comparison with traditional methods, the authors would argue that most traditional exams measure the ability of students to follow a procedural approach to determine the correct numerical value of a problem, and do not specifically test for understanding. Correct numerical answers based on procedural analysis do not ensure fundamental understanding of what is happening in thermodynamics problems. Please note some common misconceptions as gathered by Ron Miller and Ruth Streveler [24].

Common Misconceptions

Table 1: Examples of Generative Round Comments by Delphi Participants

Related to Heat Transfer Misconceptions Confusion between temperature and heat transfer. Many students believe that if the path to a state involves a heat transfer input the temperature of the system will increase – even if the heat transfer is coupled with work leaving the system.
Students do not appear to have precise understanding of heat in the sense that it is used in thermodynamics.
Students have difficulty identifying heat and work interactions between the system and the surroundings.
[Students] have trouble with work and energy relationships.
There is always student confusion about heat vs. (internal energy).
There is always student confusion about internal energy and enthalpy.
Misconception: Temperature is a measure of energy. Example: Students often believe that if you add energy, heat for example, to any system, the temperature must go up. A corollary to this is that students often believe that if the temperature goes up the energy (internal energy or enthalpy) must have increased. A good example of a system that is very confusing is an evaporative cooling process in psychometrics where the enthalpy of the moist air stays constant but the temperature decreases.
Heat, like energy, is a familiar term but its common use differs from thermodynamic definition.
Heat as transferred energy. No matter how often you make the point, some [students] insist on talking about the heat content of a system.
Confusion about the difference between heat and temperature. How can a process occur where heat is added but the temperature drops?

The authors of this paper believe that each of these common misconceptions (as expressed by thermodynamics instructors) is based on a lack of understanding that is not effectively addressed with most current teaching methods. In the concept based learning method, students must detail how energy enters, leaves, or is stored in a control volume to develop an equation for conservation of energy. To do this successfully, students need to better understand the differences between heat, work, temperature, internal energy, etc. The concept based learning method is not just a successful teaching method, the authors also believe it meets the fundamental need of gaining understanding sufficient to overcome many of these misconceptions. The authors plan to present the performance of students currently enrolled in a concept based learning section of thermodynamics on the TTCI (Thermal and Transport Concept Inventory) at the ASEE conference. Please note that the authors will not have seen the TTCI questions prior to student testing, and that no changes have been made to the teaching of the course to address the examples in Table 1.

A concept map is a graphical tool which enables students to organize and connect a concept to related topics and facts. In one study [25] concept maps were used to compare the performance of students instructed using methods for concept based learning with the performance of students instructed using traditional methods. Comparisons of instructor and student maps were completed with CMap Tools, freeware which enables the construction and subsequent analysis of concept maps. Table 2 shows that on average, a student's ability to correctly relate key thermodynamic terms increased by 17% from the initial introduction of the material to the end of the course using concept based learning. By week 3, all of the terms on the activity had been introduced to the class. The subsequent gain by week 15 is believed to come from repeated application of concepts throughout the course (which is consistent with what we know about learning).

Table 2: CMap Results: Concept based learning impact in a first semester thermodynamics course

CMap Tools (Thermodynamics 1)			
Time in Semester	*Teaching Method*	*Correct Matches*	*Instructor*
Week 3	Concept	20.4% (N = 46)	Hagge
Week 15	Concept	37.5% (N = 46)	Hagge

Table 3 indicates that at the beginning of the second course in a sequence of thermodynamic courses, on average, the ability of students to relate key terms for students taught using a concept based learning approach was 15% higher than that of those students taught using traditional methods.

Table 3: CMap Results: Concept based learning impact in a second semester thermodynamics course

CMap Tools (Thermodynamics II)			
Time in Semester	*Teaching Method*	*Correct Matches*	*Instructor*
Week 3	Concept	37.1% (N = 10)	Hagge
Week 3	Traditional	22.4% (N = 16)	Others

The data summarized in Tables 2 and 3 seem to indicate the improved understanding with concept based learning is retained until the beginning of a second thermodynamics course, at least over the 0 to 2 semester delay between the initial and subsequent course (37.5 vs. 37.1). None of the 26 students enrolled in the second thermodynamics course had previously used concept maps and had not seen the concept map activity, eliminating repeated application of the activity as a bias for improved performance. When students are first introduced to concepts (week 3, Thermo I, performance = 20.4%), they demonstrate similar performance to that at the completion of a traditional course (week 3, Thermo II, performance =22.4%). Even though students have spent 3 weeks <u>learning</u> about concepts, their <u>understanding</u> of concepts is not complete. The week 3 performance seems to indicate that it is not enough for the instructor to simply talk about concepts. The improvement from the concept based learning method comes from activities that promote *student understanding* of concepts throughout the semester.

The concept based learning method has been implemented in both a 6 week daily format and a traditional 15 week format. Comments from distance education students enrolled in the 6 week format follow.

> *"The concepts were presented very clearly and concisely with the out-of-class videos, the homeworks were useful for better understanding the material, and all problems shed light on real-life machines and processes. I also felt that the final project did a particularly excellent job of synthesizing the concepts from our entire course into a single comprehensive assignment. "I found your teaching style of helping to understand the concepts and find the few equations needed to solve the problems is more efficient then just remembering a bunch of equations and plugging and chugging. I felt that I grasped a very good concept of finding conservation of mass, conservation of energy, enthalpy, entropy, and solving for unknown properties."*

> *"I think your style of teaching is quite effective as it worked well for me."*

The Thermodynamics Concept Based course received an overall teaching effectiveness of 4.24/5.00 vs. a departmental core program undergraduate average of 3.94/5.00 in the Fall 2009 term. Below are student comments for the course in a 15 week format. Interested readers should read all of the comments, as some of these comments specifically support the claims of the authors. As an example, one of the two "needs improvement" comments was:

> *"Check the homework before giving it to the class. It is very confusing to get impractical answers. Makes me second guess my work when in fact it is correct."*

This student is clearly taking the time to determine whether or not his or her answers make sense. When confronted with answers that seem unreasonable, the students must decide if they have done something incorrectly or if the given information is unrealistic. Although this student was frustrated by the process, the important thing is that the student is *thinking* during the solution process rather than blindly accepting problem information.

Student comments Fall 2009 on Thermodynamics *Course* (15 week format):

> *"Topics covered can translate directly to real world problems. Very helpful and important class."*
>
> *"Fair grading. Learned a lot."*
>
> *"The course was good. It had a good coverage of cycles and thermo principles."*
>
> *"Too much emphasis on videos. Do more examples in class. Do examples that aren't homework problems."*
>
> *"It was one of the best classes I have ever had."*
>
> *"Enjoyable class."*
>
> *"Good teaching style, I enjoy how we learned a broad knowledge that we could use to solve any problem."*
>
> *"I struggled with the T-v diagrams. Maybe next year you could cover those in two periods."*
>
> *"I like how tests were graded based upon the process required to get the final answer rather than the final answer itself."*
>
> *"Coursework could be given back more promptly."*
>
> *"The course was good. I felt that we learned a lot of beneficial engineering applications."*
>
> *"Very effective teaching method. Related the material to actual applications very well.*
>
> *"Guidance for what would be on exams could have been a bit more thorough. Some of the exams were much harder than expected."*
>
> *"I really like that he took the time to make a DVD with additional lectures. I found these very helpful because I could re-watch them and it gave me a better understanding of the materials. Also helped me understand the lectures."*

Student comments Fall 2009 on Thermodynamics *Instructor*:

> *"Use class time more efficiently. Not a fan of videos."*
>
> *"Very helpful in class, explained topics well."*
>
> *"I think the teacher could write exams that aren't quite so time consuming or allow more time to complete the exams."*
>
> *"He was open to all questions and answered them well."*
>
> *"One of the best engineering instructors I have ever had."*

“Be a little more organized when writing on the blackboard.”

“You were very good at using class time efficiently. The concepts became clear very quickly and any questions were answered well.”

“He presented a very well understanding to the course and an excellent instructor.”

“I wish we would have went over more example problems instead of letting us out early some day. I like to learn from written examples.”

“The videos were helpful.”

“Teaching style and testing very effective.”

“Hagge was informative, to the point and overall a good teacher. The material was taught a little too quickly and I think the tests were a little too hard, but, he graded fairly.”

“Very effective style of teaching (learning concepts and ideas, not equations)

“I like your teaching style, but, I almost wish there were more practice problems assigned so I could work on them to understand the material more completely.”

Suggestions for *Improvement:*

“Longer time given on tests…..night tests? Shorter tests?”

“Check the homework before giving it to the class. It is very confusing to get in practical answers. Makes me second guess my work when in fact it is correct.”

Challenges to Concept based Teaching

This methodology works for students who would be considered advanced, moderate, and challenged using traditional methods. Interestingly, the student most likely to be resistant to concept based learning is the bright student who can, with minimal effort, earn an average grade. It may take failure on the first exam to motivate students to try a new method of learning. The emphasis of course grade must be based on the student understanding, which will require changes to the questions asked, activities, and grading methods. Those who struggle with concepts early in the course are not penalized if they demonstrate understanding by the end of the course. A student who fails the first exam can still earn an A because he or she will be tested over the same material on subsequent exams. Once struggling students believe that they are being evaluated on their ability to demonstrate understanding of concepts and realize that copying example problems and homework solutions does not give them this understanding, they begin to seek understanding and are successful by the end of the course.

6. Motivation

The following was taken from “A Test of Leadership, Charting the Future of U.S. Higher Education” commissioned by the Secretary of the Department of Education, Margaret Spellings: [26]

> *Institutions as well as government agencies have failed to sustain and nurture innovation in our colleges and universities. The commission finds that the results of scholarly research on teaching and learning are rarely translated into practice, especially for those working at the grassroots level in fields such as teacher preparation and math and science education. We also find that little of the significant research of the past decade in areas such as cognitive science, neurosciences, and organizational theory is making it into American classroom practice, whether at the K–12 level or in colleges and universities.*

And from the National Research Council’s report, How People Learn: Brain, Mind, Experience, and School [27], the following:

> *The report discusses research in six areas that are relevant to a deeper understanding of students' learning processes: the role of prior knowledge in learning; plasticity and related issues of early experience upon brain development; learning as an active process; learning for understanding; adaptive expertise; and learning as a time-consuming endeavor. The report discusses research in another five areas that are relevant to teaching and transfer and the conditions for wide application of learning; subject matter uniqueness; assessment to support learning; and the new educational technologies.*

The need to put into practice what has been learned from research about learning is apparent from these statements. This project’s goal is to examine concept based learning as an effective means of delivering material to students in ways that acknowledge and capitalize upon the physiological process of learning.

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