Mechanical Engineering Organized Around Mathematical Sophistication

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Phillip Cornwell is a Professor of Mechanical Engineering at Rose-Hulman Institute of Technology. He received his Ph.D. from Princeton University in 1989 and his present interests include structural dynamics, structural health monitoring, and undergraduate engineering education. Dr. Cornwell has received an SAE Ralph R. Teetor Educational Award in 1992, and the Dean's Outstanding Teacher award at Rose-Hulman in 2000 and the Rose-Hulman Board of Trustee's Outstanding Scholar Award in 2001. He was one of the developers of the Rose-Hulman Sophomore Engineering Curriculum, the Dynamics Concept Inventory, and he is a co-author of Vector Mechanics for Engineers: Dynamics, by Beer, Johnston, Cornwell, and Self.

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Dr. Yirong Lin is currently an Associate Professor in Department of Mechanical Engineering the University of Texas at El Paso. Before that, he was a postdoc at University of Florida and Arizona State University from 2009 to 2011. He received his Ph.D. degree in Mechanical Engineering from Arizona State University in 2009. Dr. Lin's research interests fall in design, fabrication and characterization of advanced multifunctional material systems for embedded sensing, structural health monitoring, vibration and solar energy harvesting and storage. His research encompasses micromechanics modeling, materials synthesis, structural characterization and device evaluation. The goal of his research is to develop advance structural materials for the next generation ground, aerial and space vehicles with enhanced safety and energy efficiency. He has published or submitted 49 technical articles since 2007 (25 referred journals and 24 conference proceedings). Dr. Lin's teaching interests lies in Mechanical Design, Solid Mechanics, and Dynamics. Currently, he is advising 4 Ph.D. students, 3 Master students, and 2 undergraduate students. Since 2011, 5 Master students graduated from his group. He was awarded the Best Paper at SAMPE 2008 fall technical conference, Honorable Mentioned Best Student Paper at SMASIS 2009 fall conference and ASME Best Paper in Materials of 2010 at SPIE Smart Materials/NDE 2011 conference. He is a member of ASME, SPIE, SAMPE and AIAA.

Dr. Norman Love, University of Texas, El Paso

Norman D. Love, Ph.D.is an Associate Professor in the Department of Mechanical Engineering. Dr. Love earned a B.S. and M.S. in Mechanical Engineering from the University of Texas El Paso and completed his Ph.D. at the University of Oklahoma in the same field. Dr. Love's research interests lie in the areas of propulsion, energy, and engineering education. He has developed flipped classroom modules and also implements project based learning activities in his class activities.

Mechanical Engineering Organized Around Mathematical Sophistication

This paper describes a work in progress. It is applying a proven, NSF funded problem-solving approach to a new and important demographic of underrepresented minority students. Those that aspire to become engineering majors, but are not calculus ready. The work will determine if it increases success for that population. The intervention, called the Conservation and Accounting Principles or CAP, is applicable to all Engineering Science (ES) [1]. The CAP unifies the approach to ES problems and has Algebraic, Trigonometric and Calculus formulations. The CAP allows a student to solve real world (Authentic) problems in all the traditional Mechanical Engineering domains (statics, dynamics, strength, fluids, circuits and thermodynamics) [2]. By using the algebraic formulation of CAP, students can begin and advance in engineering study while they work toward learning Calculus. This will allow students to progress toward their degree while strengthening their mathematics abilities.

In contrast, advancing in a typical Engineering curriculum requires the student to enroll in Calculus, because MOST Engineering courses contain SOME content that uses Calculus [3]. Some courses require no calculus like Graphics and Professionalism Ethics courses but exceptions are few. This means a matriculate ill prepared to study Calculus must catch up on mathematics BEFORE starting Engineering study. This can add one to two years to the degree.

This work is redesigning the first two years of a Mechanical Engineering Degree Program. It hopes to demonstrate that CAP can present authentic ES content sorted by required mathematical sophistication. It hopes to show that students who are not Calculus ready can advance through an Engineering program while they prepare for Calculus. It will hopefully prove that the number of STEM graduates increases by keeping ill prepared entering students engaged in STEM long enough for them to improve their mathematical abilities.

Although this is a work in progress it is important to describe the work early. The project leaders are looking for external advice. Readers who believe the work is important are encouraged to contact the first author; they will be provided with information about the design and implementation as it proceeds. There is no obligation on these external advisors and unfortunately there is no financial incentive either.

The Big Picture

Data [3] shows that the obstacles faced by entering **M**athematically **U**nder**p**repared MUP students majoring in Engineering result in high attrition. Common wisdom is that one can do nothing to bring these poorly prepared matriculates into the fold. However, the authors bring a unique and proven method of engineering problem solving (the Conservation and Accounting Principles or CAP[1]) to bear on the problem.

Most faculty recognize that problem solving is crucial skill for engineers and therefore a major thread within engineering; however, to the average student, different courses appear to have different problem-solving techniques. Before students can begin to solve a problem, they must

[1] The paper will explain CAP later. For now, think of it as unifying all Engineering Science.

carefully read the problem statement. Before they can do any analysis, they typically develop a mathematical **model**. To do this, they need to isolate a part of the physical world and identify the **system**. Next, they describe the **state** of the system and identify its important **properties**. Then they identify the **processes** that change the state of the system and the **interactions** the system has with its surroundings during these processes. Finally, they apply the fundamental principles or laws [2].

A significant problem for students is that each of the general ideas identified in bold above have different names and procedures in each course. For example, the simple idea of a system is a “free-body diagram” in statics and dynamics, a “node” in electrical engineering, a “system” in thermodynamics, and a “control volume” in fluid mechanics. This example of the different names used in each class is just a simple example of the differences [4].

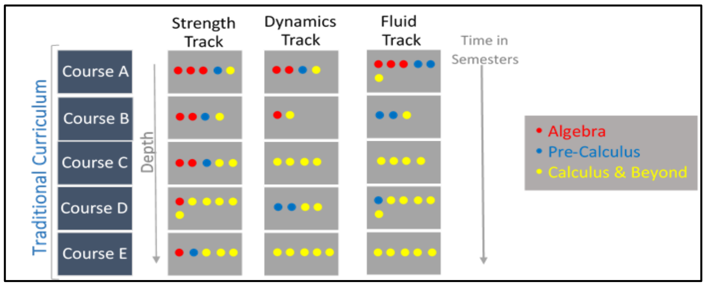


Figure 1 – Graphical Representation of a "Typical" ME Curriculum.

The big picture of the work is shown graphically using Figures 1 through 3. Figure 1, shows a “traditional” ME curriculum. It shows three “tracks” (Strength, Dynamics and Fluids). Traditionally, courses in the tracks use similar notation and problem-solving approaches but across tracks, methodology and notation can differ significantly as explained in the previous paragraph. In the figure, each horizontal box is a course (15 are shown). Colored dots inside each course indicate the mathematical sophistication required for an idea or concept in the course. Note that courses can, and do, contain ideas with varying levels of sophistication. The figure depicts all entry-level track courses requiring some calculus[2] and this means MUP students could not begin this curriculum until they have sufficient calculus.

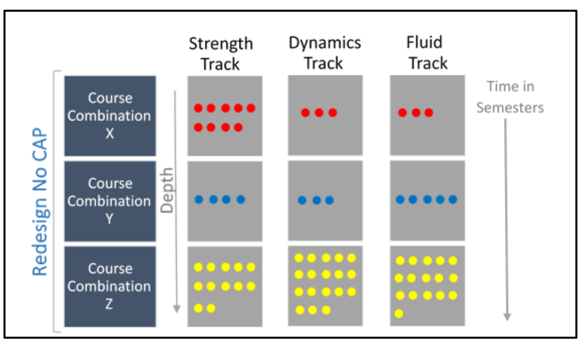


Figure 2 – Graphical Representation of a non-CAP Re-design.

Figure 2 shows a “possible” intermediate non-CAP re-design of a curriculum. In this design, the introductory classes contain concepts that only require algebra so MUP students can immediately use them. Note that there are still tracks because the methodology and notations used for each track differ so it would be difficult to combine them. The problem with this organization is that there may be insufficient “algebra only” or “trig only” material to produce entry-level or second level courses in each track. The figure depicts this by the few red and blue dots in some classes.

Figure 3 shows the design used in this work. CAP consolidates the tracks together into a “single” track. This ensures there is sufficient content available at all mathematical levels to create full courses. In addition, the CAP, when used with traditional students, demonstrated increased

[2] Not all entry-level courses require calculus. Graphics is a good example. However, there are not many algebra only Engineering classes so non-Calculus ready students cannot advance far.

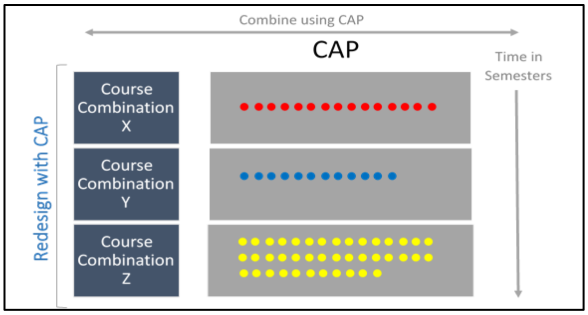


Figure 3 − Graphical Representation of Curriculum Re-design Using CAP.

understanding and success. Our work is expected to demonstrate similar gains for the MUP group.

The work being reported is re-designing the first two years to allow MUP students to advance in engineering while studying below-calculus mathematics. These years will blend back into a traditional curriculum in the third- and fourth-years.

The CAP Approach

Engineering curricula usually begin with courses in mathematics and science, typically calculus, physics and chemistry. These are followed by the engineering science core courses that are intended to provide students with a foundation in fundamental principles needed for engineering analysis and the strong problem-solving skills required for upper-level courses that focus on discipline-specific material. Unfortunately, the engineering science core is often perceived by students as unrelated chunks of information that have unrelated problem-solving techniques and terminology [4].

CAP provides a unifying framework for teaching the core engineering science courses. It does this by reframing the underlying physical principles using a common, consistent approach that emphasizes the similarities between the material in different courses which is usually unseen by students and not acknowledged by faculty [1]. When exposed to this approach, many faculty recall an “aha” moment in graduate school where the common structure underlying engineering suddenly became apparent. One of the goals of using the CAP framework is to help students see this early in their career and use this framework to organize their learning and problem solving.

History of CAP

In 1988, a group of faculty at Texas A&M University began work on a new integrated engineering curriculum to replace the core engineering science courses in a typical curriculum. The result was an interdisciplinary sequence of four courses called the Texas A&M/NSF Engineering Core Curriculum, which was organized around what they called the Conservation and Accounting Principles [5]). Glover and colleagues produced an introductory textbook that used this approach [6].

In 1993, seven schools came together as the Foundation Coalition (FC) under the auspices of the NSF Engineering Education Coalitions Program. One of the major thrusts of the FC was curriculum integration. Building on the earlier work at Texas A&M, Rose-Hulman developed a new sophomore engineering curriculum—the Rose-Hulman/Foundation Coalition Sophomore Engineering Curriculum (SEC) [7]. This curriculum also used CAP as an organizing principle. Taught continuously since 1995, the one constant in the SEC has been its foundational course, Conservation & Accounting Principles, that sets the stage for the rest of the curriculum. A textbook to support this course was also produced [8].

Other institutions have also used this approach. Holtzapple introduced this approach in a text to support an Introduction to Engineering course for freshmen [9]. The late Prof. William C. Reynolds at Stanford University also promoted and developed a similar approach for a lower-level course called ME10: Introduction to Engineering Analysis [10]. Rice University has used a similar approach as the organizing principle for a first biomedical engineering course using a text written by Saterbak, San, and McIntire [11]. Calls to consider a systems approach have also come from physicists [12], [13]. Physicists at the University of Karlsruhe in Germany have developed a complete high-school physics curriculum using this approach [14]. Two other universities have developed engineering curricula using this approach. The University of New Haven developed a spiral curriculum that begins with a conservation and accounting course [15], and the University of Western Australia has recently revised their engineering curriculum to emphasize threshold concepts and found that the CAP approach aligns well with this framework [16].

CAP has shown improved student learning

The mechanics portion of the SEC at Rose-Hulman Institute of Technology was assessed using identical final exams that were given to students in the SEC and students taking a traditional dynamics course [17]. The two courses were taught by the same professor using similar pedagogical methods; therefore, the primary difference was the presentation of the material in a CAP framework versus the traditional approach used in most dynamics courses. Both finals consisted of 20 multiple-choice problems (40% of the total points) and 3 workout problems (60% of the total points). Students' performance on the multiple-choice problems was not statistically different, but students in the new curriculum were found to perform significantly better on the longer, more complicated workout problems as shown in Table 1. This data was taken many years ago and we no longer have it, but there were approximately 125 students in a traditional dynamics class and 100 in the SEC.

Table 1 Percentage of students with correct answers for the workout problems (1997-1998 academic year)

Workout problem number	Students in the SEC	Students in traditional dynamics class	Difference
1	36.8	17.0	19.8
2	70.1	22.0	48.1
3	46.0	6.0	40.0

In addition to improved student learning, the foundational course of the SEC at Rose-Hulman, ES201 – Conservation and Accounting Principles, has had a profound influence on the faculty members who teach it [18]. In this paper, survey results indicate strong faculty support for this course and a strong belief in the benefits of the unified framework. In the survey comments, faculty members expressed the view that ES201 was the foundational course for all other mechanical engineering courses. Also, 88% of the faculty responding to the survey indicated that teaching this course has had a strong influence on how they teach their other courses.

Overview of the approach

CAP provides a common framework for the basic principles and a structured problem-solving approach. The underlying organizing principle for CAP is the accounting principle. The key idea is that every system has extensive properties associated with it and that the behavior of the system can be determined by monitoring changes in these properties. Any change in an extensive property within the system can be accounted for by counting the amount of the extensive property transported across the system boundary and the amount generated or consumed inside the system [18].

Given a generic extensive property *B*, e.g. mass or energy or momentum or charge or entropy, it is possible to write a general accounting principle for any system. In its simplest form, the finite time version of the accounting principle is very intuitive and can be written as:

$$\underbrace{\begin{bmatrix}\text{Amount of } B\\ \text{inside}\\ \text{system}\\ \text{at the end of}\\ \text{time period}\end{bmatrix} - \begin{bmatrix}\text{Amount of } B\\ \text{inside}\\ \text{system}\\ \text{at the start of}\\ \text{time period}\end{bmatrix}}_{\substack{\text{Accumuation of } B \text{ inside}\\ \text{system during time period}}} = \underbrace{\begin{bmatrix}\text{Amount of } B\\ \text{transported}\\ \text{into system}\\ \text{during}\\ \text{time period}\end{bmatrix} - \begin{bmatrix}\text{Amount of B}\\ \text{transported}\\ \text{out of system}\\ \text{during}\\ \text{time period}\end{bmatrix}}_{\substack{\text{Net amount of } B \text{ transported into}\\ \text{system during time period}}} + \underbrace{\begin{bmatrix}\text{Amount of } B\\ \text{generated}\\ \text{inside system}\\ \text{during}\\ \text{time period}\end{bmatrix} - \begin{bmatrix}\text{Amount of } B\\ \text{consumed}\\ \text{inside system}\\ \text{during}\\ \text{time period}\end{bmatrix}}_{\substack{\text{Net amount of } B \text{ generated inside}\\ \text{system during time period}}}$$

The “rate form” of the accounting principle is the same as the equation above but uses the rate of accumulation, transport, and generation. For an extensive property that is conserved, there is no generation or consumption. The usefulness of the accounting principle is that it provides a common framework for presenting and applying the fundamental laws of physics routinely used by engineers. Although not traditionally presented this way for undergraduates, all of these laws can be formulated as conservation or accounting principles [18]. Table 2 shows the rate form of the conservation and accounting principles.

Table 2 RATE Form of Conservation and Accounting Equations.

Principle	Governing equation in rate form
Conservation of mass	$\frac{dm_{sys}}{dt} = \sum_{in} \dot{m}_i - \sum_{out} \dot{m}_e$
Conservation of charge	$\frac{di_{sys}}{dt} = \sum_{in} \dot{q}_i - \sum_{out} \dot{q}_e$
Conservation of linear momentum	$\frac{d\mathbf{P}_{sys}}{dt} = \sum_{ext} \mathbf{F} + \sum_{in} \dot{m}_i \mathbf{v}_i - \sum_{out} \dot{m}_e \mathbf{v}_e$

Conservation of angular momentum	$$\frac{d\mathbf{L}_{sys_A}}{dt} = \sum_{ext} \mathbf{M}_A + \sum_{in} \mathbf{r} \times \dot{m}_i \mathbf{v}_i - \sum_{out} \mathbf{r} \times \dot{m}_e \mathbf{v}_e$$
Conservation of energy	$$\frac{dE_{sys}}{dt} = \sum \dot{Q} + \sum \dot{W} + \sum_{in} \dot{m}_i \left(h + \frac{v^2}{2} + gz\right)_i - \sum_{out} \dot{m}_e \left(h + \frac{v^2}{2} + gz\right)_e$$
Accounting of entropy	$$\frac{dS_{sys}}{dt} = \sum \frac{\dot{Q}_j}{T_j} + \sum_{in} \dot{m}_i s_i - \sum_{out} \dot{m}_e s_e + \dot{S}_{gen}$$

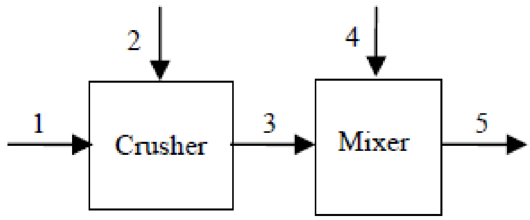
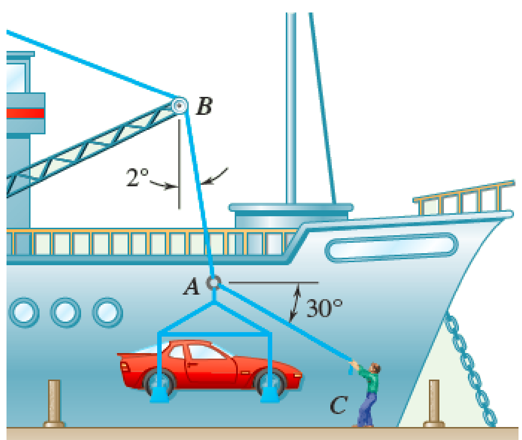
At first glance, these equations can look very complicated. However, it is important to remember that when teaching these, we start with the very intuitive conservation of mass, and then slowly add the more complicated principles. We often make simplifying assumptions such as that the system is operating at steady state. Other schools have had no problem with students understanding and applying these principles.

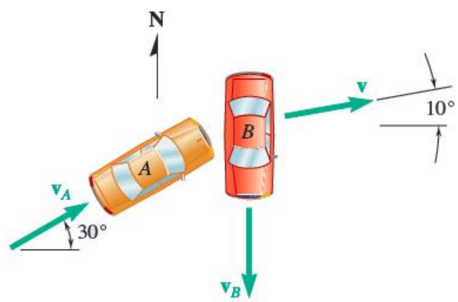
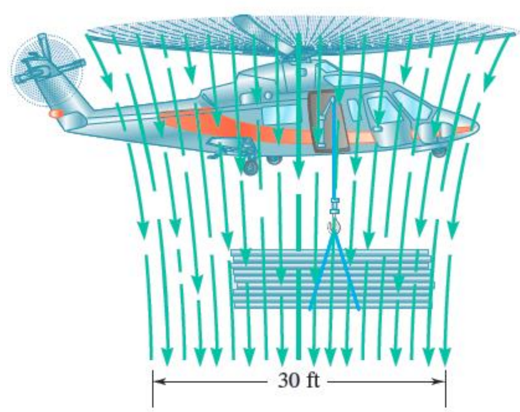
One of the advantages of using the conservation and accounting framework is that it lends itself to the use of a common problem-solving approach regardless of the problem. When a student is faced with a problem, he or she has a consistent set of questions to ask about the problem such as "What is my strategy?", "What system should I choose?", "What conservation principle or principles is applicable", "Is the amount changing in the system?", "Is it being transported across the system boundary?", etc. Because students are asked to construct their solutions beginning with the basics, they must now focus on how the modeling assumptions simplify the general equations instead of looking for the already simplified equation in the text [18].

Types of problems that can be solved using the CAP approach

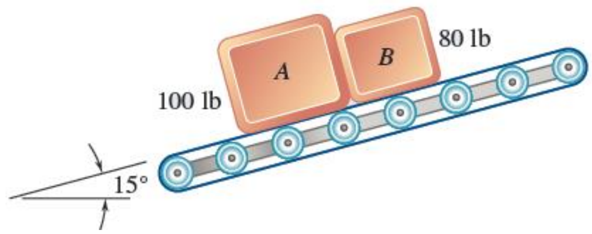
In Table 3 is shown a representative sample of the types of problems that are solved in the foundational CAP course at Rose-Hulman. The details of each problem are not provided due to space limitations, but none of these problems require calculus.

Table 3 Sample problems that do not need Calculus and can also be solved in an introductory course using the CAP approach.

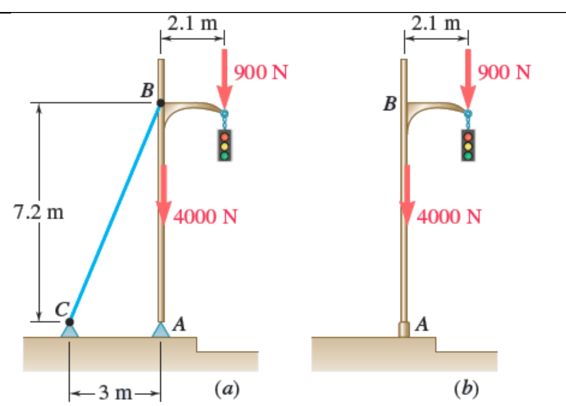
CAP	General description (all the details are not given)	Schematic	Assumptions/ Notes
Conservation of Mass (Rate)	The ItsaVegetable Co. makes ketchup for school lunchrooms using a two-stage process. Given some flowrates and composition data, find unknown flowrates and compositions.	 	Steady state No chemical reactions
		$\underbrace{\frac{dm_{sys}}{dt}}_{0} = \sum \dot{m}_i - \sum \dot{m}_e$	
CAP	**General description (all the details are not given)**	**Schematic**	**Assumptions/ Notes**
Conservation of Linear Momentum (Rate)	In a ship-unloading operation, a automobile is supported by a cable. A worker ties a rope to the cable at *A* and pulls on it in order to center the automobile over its intended position on the dock. What are the tensions in the rope and cable?	 	Steady state Closed
		$\underbrace{\frac{d\vec{P}_{sys}}{dt}}_{0} = \sum \vec{F} + \underbrace{\sum \dot{m}_i \vec{v}_i}_{0} - \underbrace{\sum \dot{m}_e \vec{v}_e}_{0}$	

CAP	General description (all the details are not given)	Schematic	Assumptions/ Notes
Conservation of Linear Momentum (finite)	At an intersection, car *B* was traveling south and car *A* was traveling 30° north of east when they slammed into each other. Which car was speeding?		Closed
		$\Delta\vec{P}_{sys} = \vec{P}_{sys_2} - \vec{P}_{sys_1} = \sum \vec{F}\Delta t + \sum \cancelto{0}{\dot{m}_i\vec{v}_i\Delta t} - \sum \cancelto{0}{\dot{m}_e\vec{v}_e\Delta t}$	
CAP	**General description (all the details are not given)**	**Schematic**	**Assumptions/ Notes**
Conservation of Linear Momentum (rate)	The helicopter shown can produce a maximum downward air speed. Determine the maximum load that the helicopter can lift while hovering in midair.		Steady state
		$\cancelto{0}{\frac{d\vec{P}_{sys}}{dt}} = \sum \vec{F} + \sum \dot{m}_i\vec{v}_i - \sum \dot{m}_e\vec{v}_e$	

<table>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Conservation of Linear Momentum (rate)</td><td rowspan="2">Boxes A and B are at rest on a conveyor belt that is initially at rest. The belt is suddenly started in an upward direction so that slipping occurs between the belt and the boxes.

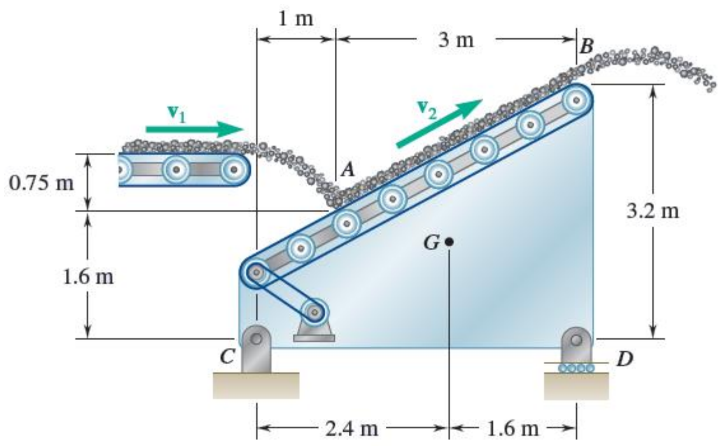
Determine the acceleration of each box.</td><td>
</td><td>Closed

Will need two systems</td></tr>
<tr><td colspan="2">$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum \dot{m}_i \vec{v}_i - \sum \dot{m}_e \vec{v}_e$$ $\frac{d\vec{P}_{sys}}{dt} \to m\vec{a}$, $\sum \dot{m}_i \vec{v}_i \to 0$, $\sum \dot{m}_e \vec{v}_e \to 0$</td></tr>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Conservation of Linear and Angular Momentum (rate)</td><td rowspan="2">A traffic-signal pole may be supported in the two ways shown.

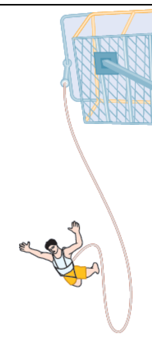
Determine the reactions for each type of support shown.</td><td>
</td><td>Steady state

Closed</td></tr>
<tr><td colspan="2">$$\frac{d\vec{P}_{sys}}{dt} = \sum \vec{F} + \sum \dot{m}_i \vec{v}_i - \sum \dot{m}_e \vec{v}_e$$ $\frac{d\vec{P}_{sys}}{dt} \to 0$, $\sum \dot{m}_i \vec{v}_i \to 0$, $\sum \dot{m}_e \vec{v}_e \to 0$ $$\frac{d\vec{L}_{sys_A}}{dt} = \sum \vec{M}_A + \sum \vec{r} \times \dot{m}_i \vec{v}_i - \sum \dot{m}_e \vec{v}_e$$ $\frac{d\vec{L}_{sys_A}}{dt} \to 0$, $\sum \vec{r} \times \dot{m}_i \vec{v}_i \to 0$, $\sum \dot{m}_e \vec{v}_e \to 0$</td></tr>
</table>

<table>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Conservation of Linear and Angular Momentum (rate)</td><td rowspan="2">Coal is being discharged from a first conveyor belt at a known mass flow rate.

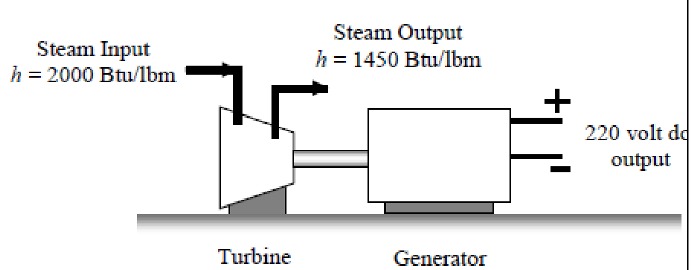
Determine the reactions and C and D.</td><td>
</td><td>Steady-state</td></tr>
<tr><td colspan="2">$$\cancelto{0}{\frac{d\vec{P}_{sys}}{dt}} = \sum \vec{F} + \sum \dot{m}_i \vec{v}_i - \sum \dot{m}_e \vec{v}_e$$
$$\cancelto{0}{\frac{d\vec{L}_{sys_A}}{dt}} = \sum \vec{M}_A + \sum \vec{r} \times \dot{m}_i \vec{v}_i - \sum \dot{m}_e \vec{v}_e$$</td></tr>
</table>

<table>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Energy (finite)</td><td rowspan="2">An elastic cable is to be designed for bungee jumping from a tower.

Determine the spring constant k.</td><td></td><td>Closed

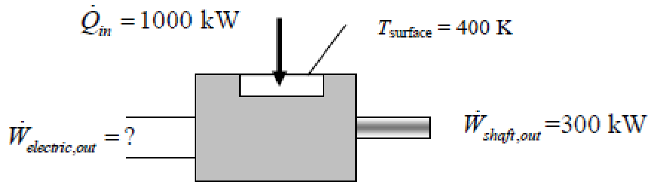
Adiabatic

No work</td></tr>
<tr><td colspan="2">$$\frac{dE_{sys}}{dt} = \sum \dot{Q} + \sum \dot{W} + \sum \dot{m}_i\left(h+\frac{v^2}{2}+gz\right)_i - \sum \dot{m}_e\left(h+\frac{v^2}{2}+gz\right)_e$$
0 0 0 0
So
$$E_{sys_2} - E_{sys_1} = 0$$</td></tr>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Energy (rate)</td><td rowspan="2">A dc-electric generator is attached directly to a steam turbine.

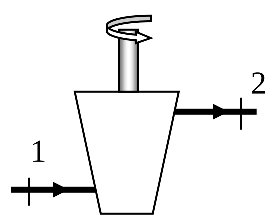
Determine the electric power, dc current, and the torque.</td><td></td><td>Turbine:
Adiabatic
Steady state

Generator:
Closed,
Steady state</td></tr>
<tr><td colspan="2">$$\frac{dE_{sys}}{dt} = \sum \dot{Q} + \sum \dot{W} + \sum \dot{m}_i\left(h+\frac{v^2}{2}+gz\right)_i - \sum \dot{m}_e\left(h+\frac{v^2}{2}+gz\right)_e$$
0
(the other terms that are zero depends on the system chosen)</td></tr>
</table>

<table>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Entropy and Energy (finite)</td><td rowspan="2">An inventor claims to have developed a new device that operates at steady-state conditions and produces both shaft power and electrical power.

Is the device possible?</td><td>
</td><td>Closed

No work</td></tr>
<tr><td colspan="2">$$\frac{dE_{sys}}{dt} = \sum \dot{Q} + \sum \dot{W} + \sum \dot{m}_i \left(h + \frac{v^2}{2} + gz\right)_i - \sum \dot{m}_e \left(h + \frac{v^2}{2} + gz\right)_e$$
0 0 0
and
$$\frac{dS_{sys}}{dt} = \sum \frac{\dot{Q}_j}{T_j} + \sum \dot{m}_i s_i + \sum \dot{m}_e s_e + \dot{S}_{get}$$
0 0 0 0</td></tr>
<tr><th>CAP</th><th>General description (all the details are not given)</th><th>Schematic</th><th>Assumptions/ Notes</th></tr>
<tr><td rowspan="2">Entropy and Energy (finite)</td><td rowspan="2">A stream of high pressure fluid flows through a fluid expander to extract power.

Determine power generated and entropy generation rate when the fluid is air and when the fluid is water.</td><td>
</td><td>Closed
No work
Adiabatic</td></tr>
<tr><td colspan="2">$$\frac{dE_{sys}}{dt} = \sum \dot{Q} + \sum \dot{W} + \sum \dot{m}_i \left(h + \frac{v^2}{2} + gz\right)_i - \sum \dot{m}_e \left(h + \frac{v^2}{2} + gz\right)_e$$
0 0
and
$$\frac{dS_{sys}}{dt} = \sum \frac{\dot{Q}_j}{T_j} + \sum \dot{m}_i s_i + \sum \dot{m}_e s_e + \dot{S}_{get}$$
0 0</td></tr>
</table>

Example From Multiple Tracks

To better understand the unifying ability of the CAP method consider the following problems. First consider Figure 4. A reasonable problem involving only algebra could be given as follows. If the smooth slider has the speed shown at point A, what is the maximum distance s that it can reach?

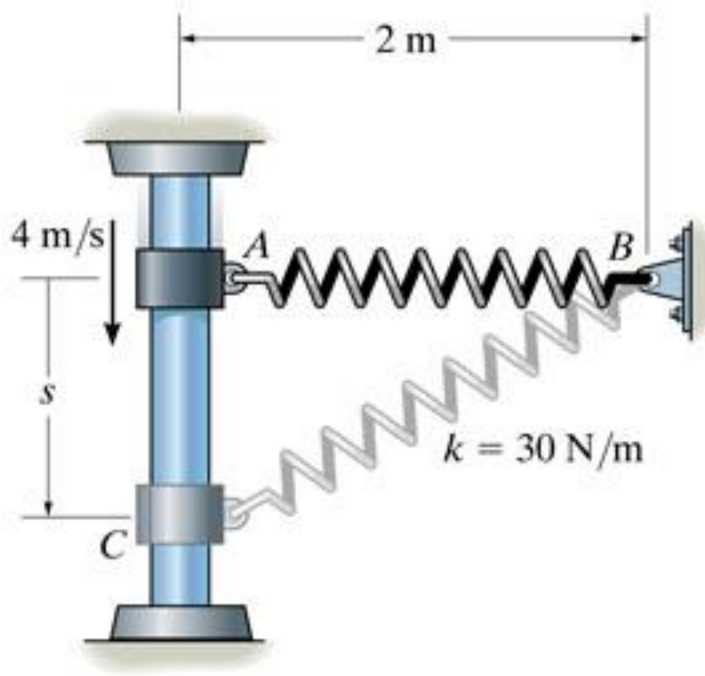


Figure 4 - Example of a Problem in Mechanics.

Solving this problem requires an understanding of kinetic and potential energy and how to account for it in a system.

Similarly consider Figure 5 showing a tank of water connected to a nozzle. Given all the dimensions, a reasonable question might be to determine the pressure at the throat of the nozzle. Again this problem requires an understanding of how to account for energy in a system. It has different forms of energy when compared to the mechanics problem but the problem set up and solution can be handled in the same way.

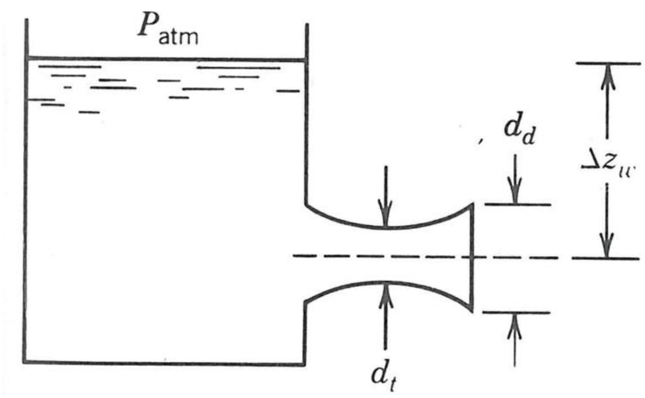


Figure 5 - An Energy Problem in the Fluid Track.

Finally consider the thermodynamic problem shown in Figure 6. Given that the system is adiabatic (no heat transfer) a question might be to determine the mass flow rate. This is another energy accounting problem like the previous two. It is more complex because the energy in the system is taking on many forms and the relations between temperature/pressure and energy are very complex but it is an energy accounting problem and has similar approach as the previous two.

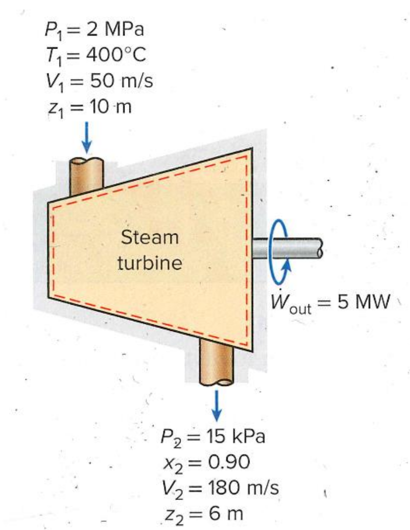


Figure 6 - A Thermodynamic Problem Involving Energy.

Impact on Accreditation

The authors do not anticipate any accreditation issues with this approach. ABET criteria does not dictate specific organization of the curriculum. The curriculum is expected to cover all the basics of a traditional Mechanical Engineering curriculum so the content should satisfy accreditation. The curriculum is also expected to provide increased understanding for students. Previous data indicated this was the case when CAP was used for a more traditional student so the authors hope that CAP will provide similar learning gains. If this is the case, the accreditation board should have no issue with it.

Finally, ABET encourages sound, well thought out, and well assessed curriculum changes by encouraging continuous improvement.

Concluding Remarks and How to Participate

This paper has described an **innovative approach** to improve STEM education that begins with an **evidence-based method proven successful** on one demographic and will **generate knowledge** about the method's efficacy on a new, underrepresented demographic.

The authors expect to demonstrate a significant increase in Engineering graduates but there are risks. Even if all students recruited for this project are sincere about interest in Engineering, not all will graduate with a STEM degree. However, we believe that by strengthening problem solving abilities of all participating students, the students will be more **technologically literate** therefore those leaving STEM will contribute to the scientific literacy of the general population. The CAP approach has a proven record for increasing conceptual understanding of ES partially because it allows more instruction time to be spent on understanding principles and requires less time for methods and tricks [18]. CAP produces students better able to think critically about Technology Concepts. Exposure to CAP will prepare a more **Technology Literate** person. Hence MUP students who graduate in Engineering increase the number of STEM graduates. Those MUP who choose other majors increase the number of Technology Literate citizens.

This work is much more than new courses, or a new curriculum or even more STEM graduates. The true benefit is the new knowledge about educating MUP students. The work hopes to show for students who struggle with Mathematics that using unique strategies and innovative approaches will enable them to be successful.

Any reader interested in this topic is encouraged to contact the first author. Although there is no financial incentive to participating, external readers will have immediate access to both the generated materials and assessment data. They will also have the ability to give formative feedback directing the evolving work which may make it easier to apply the results at their institution. Readers from industry and government are also encouraged to participate.

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