Innovative Approach to Teaching and Learning Introductory Undergraduate Physics for Engineering using EES.

Guido W. Lopez
Northeastern University
Boston, MA

ABSTRACT

Physics is a foundation subject of several engineering disciplines, such as, mechanical, electrical, electronic, chemical, aeronautical, aerospace, automotive, nuclear, etc. As such, the learning of physics by engineering students requires a suitable level of cognitive skill to think conceptually and project the technological initiatives that can be found behind its principles. In effect, a good grasp of the concepts of science inherent to a particular engineering discipline provides a reliable and firm scaffold to engineering students for the practice of their profession. Quite often, however, the teaching of undergraduate physics in engineering programs emphasizes manipulation of formulas and numerical computation instead of deep understanding of inherent concepts. This "cookbook" approach seriously affects the strength of the scientific foundation that physics courses need to provide to engineering students. The use of computer software in the classroom helps to minimize this problem substantially. In effect, much of the tedious manipulative and computational burden that are typical of in-class, exam, or take-home problems in physics, can now be effectively and quickly executed by computer software. This approach frees time for instructors to emphasize concepts instead of procedures and helps students to master the underlying science of their engineering disciplines with greater confidence and efficacy. This paper presents a comparative study between a traditional approach to teaching engineering physics, and an innovative approach that uses the computer software EES (acronym for Engineering Equation Solver), to convey concepts and principles of physics by minimizing mathematical manipulation and computational burden associated with the practice of problem-solving. This new approach and examples presented here have been used and tested on the instruction of engineering students taking introductory physics at Northeastern University. Preliminary evaluation of their performance suggest that the computational power of the computer software EES greatly helps engineering students to gain a deeper understanding of the fundamental concepts and principles taught in introductory undergraduate physics.

Introduction.

Science and technology are different from each other on their purposes. Nevertheless, the foundation of present technology can only be found in the landmark ideas, the logic and the predictive power of science. Engineering is the discipline that prepares professionals to support and advance technology. Engineering uses the findings of science to provide solutions to human needs. Therefore, effective engineering training requires the proper comprehension of concepts and principles of nature discovered by inductive or deductive science and tested by factual evidence.

Physics is recognized as the most basic of all science disciplines and has become part of the educational mainstream for engineering. Physics is a foundation subject quite common in engineering curricula. Important introductory concepts and principles of science are normally provided to engineering students through physics courses during the first and/or second year of their curricula, and they cover basic aspects of science such as motion, forces, energy, heat, sound, light and the constituents of matter. Often, however, introductory physics for engineers emphasizes computation and manipulation of formulas missing the most important objective of this foundation subject, i.e., the essential comprehension of the concepts. This "cookbook" approach seriously affects the strength of the scientific foundation that physics courses need to provide to engineering students. Furthermore, many engineering students find physics to be an unfortunate roadblock of their training instead of an indispensable element that shapes their analytical thinking.

When following a computational approach instead of a conceptual one, the teaching and learning of introductory physics in engineering curricula becomes a "recipe" process. Important concepts and principles of science become a mathematical "formula" to alleviate engineering headaches instead of factual reality. Mathematics itself is no longer perceived as the language of science and the path to logical thinking, but a tedious and cumbersome group of symbols and processes representing fuzzy and ambiguous ideas disconnected from the scientific roots of engineering.

At present, the use of computer-based instruction is becoming a widespread practice in undergraduate education. Indeed, computers are proving to be an indispensable tool in the classroom to enhance the educational experience of students and instructors. Considerable efforts are being made by educational institutions to provide the required infrastructure in the classroom in order to facilitate the use of computers by instructors and students in the classroom. Nonetheless, there is still a great deal of apprehension within the academic community in regard to the real benefits of computer-based education.

This paper discusses some benefits derived from incorporating the use of computer software for teaching important concepts of introductory physics to engineering students. Computer software can be shown to reduce substantially the time spent on computational procedures inherent to the solution of example and exercise problems utilized to understand conceptually the fundamental ideas of science. In effect, much of the tedious manipulative and computational burden that are typical of in-class, exam, or take-home problems in physics, can now be effectively and quickly executed by computer software. This approach frees considerable time for instructors to emphasize concepts instead of procedures and helps students to master the underlying science of their engineering disciplines with greater confidence and efficacy.

A comparative study is presented here between a traditional approach to illustrate concepts of engineering physics, and an innovative approach that uses the computer software EES (acronym for Engineering Equation Solver), to convey these concepts and principles with minimum mathematical manipulation and computational burden associated with the practice of problem-solving. The new approach and examples presented here have been used and tested on the instruction of engineering students taking introductory physics at Northeastern University. Preliminary evaluation of their performance suggests that the computational power of the computer software EES greatly helps engineering students to gain a deeper understanding of the fundamental concepts and principles taught in introductory undergraduate physics and develop a better appreciation for their relevance in the engineering disciplines.

Software Selection.

The distinguishing characteristic of engineering is the ability to solve technical problems aiming to satisfy human needs. Computer software can facilitate and speed substantially the solution of technical problems. Engineering students can greatly benefit from early exposure to computer software as an effective tool for comprehending more effectively the underlying subjects of science. A great number of science and engineering texts now include resource computer software that can be used as an aid to convey the subject matter. One of these computer packages is the EES software, a software program developed by S. Klein and W. Beckman from the University of Wisconsin-Madison. EES is an acronym for Engineering Equation Solver and has been selected in this study to discuss the benefits of incorporating computer software for teaching introductory areas of physics. The EES program was chosen because it is intuitive and simple to use, and has been developed with features of noticeable relevance to engineering training.

EES is an equation solver with built-in functions for thermophysical properties. With EES, therefore, it is no longer necessary to use tabulated information from texts or handbooks in a wide variety of physics problems. In general, EES can be used to solve algebraic, differential and integral equations, check unit consistency, do optimization and uncertainty analyses, provide linear and non-linear regressions, and generate two and three dimensional plots. The inherent capabilities of EES become handy at the moment of solving example, exercise or homework problems during the teaching and learning of introductory physics subjects. One important characteristic of EES, however, is that it does not solve problems for the user. It is the user that solves the problems based on the conceptual understanding of the subject matter. Therefore, a firm grasp of the principles and concepts is essential for developing the structure of the solution and for obtaining correct results. But, the manipulative burden of equations and computational procedures is greatly reduced if not totally eliminated by using EES.

EES is a window-based software. The structure of mathematical formulas and procedures aiming to solve physics problems are written on an "equations window" in an intuitive format. The user develops this structure based on the proper conceptual and logical thinking that reflects the nature of the problem. Subsequently, the computer takes charge to manipulate equations as needed (variable substitution, elimination, etc), and perform the calculations that lead to an answer. The software is capable to check for dimensional homogeneity, and it will prompt the user to check units if related inconsistencies are detected.

Study Cases.

Three typical problems of introductory physics are selected and discussed in this paper to illustrate the benefits of using computer software as innovative pedagogical approach. These problems are intimately related to important introductory concepts and principles of science that engineering students need to comprehend adequately starting early in their undergraduate curricula, in areas such as: motion, matter, force, energy, and electricity. The applicability of the software-approach to teaching and learning physics, however, can be extended essentially to all introductory concepts discussed in introductory engineering physics.

The first study case is related to the motion of bodies. This is a problem that can be used as an illustrative exercise, homework assignment, or for testing students on important principles, concepts and definitions in the area of kinetics of particles. The statement is as follows:

*In the system shown cylinders A and B have a mass of 5.00 kg each while the mass of cylinder C is 10.0 kg. Initially, all blocks are at rest. Now, a constant downward vertical force **F** is applied to block B as shown, and the system starts moving. Block B is observed to move vertically through 2.50 m in 2.00 s. Find the magnitude of the applied force **F**, and the tension in the cord **c-d**. Consider the weights of the pulley, the mass of the cables and frictional effects to be negligible. Also, assume the cables do not stretch and that the acceleration of gravity is directed downward.*

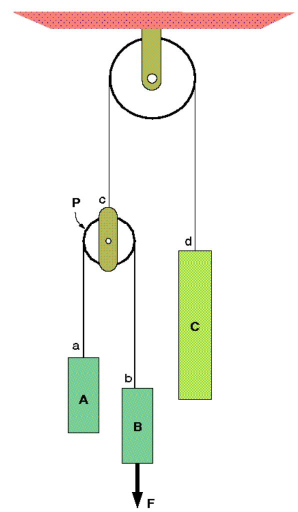


Figure 1.- System of moving cylinders and pulleys

The central principle behind the solution of this problem is obviously Newton's Second Law of motion.

$$\mathbf{F} = \frac{d}{dt}(m\,\mathbf{v}) \qquad (1)$$

Where;

F = force
m = mass
v = velocity

The clear understanding of this principle will point students toward the solution. Therefore, from the mathematical perspective Equation 1 is the instrumental guide of thought to obtain an answer. However, to arrive at the answer, it is necessary to structure a solution path that requires a clear comprehension of other additional concepts, definitions and relationships.

Words such as *mass, time, weight, tension, gravitational acceleration, speed, relative motion, and kinematics*, are also an important part of this problem, and students need to develop the proper insight to discern the embedded concepts behind their semantics, as well as, understand the natural relationship among these concepts. Additional requirements are the rules and techniques of mathematical communication that facilitate clarity and correctness of the solution path.

In a "conventional" approach to solve this problem, considerable time and effort needs to be dedicated to write and organize equations, perform numerical computations, check correctness of units, and collect additional data that is assumed to be easily accessible or memorized by students. In contrast, using the "software" approach, this time is dedicated to explain, understand and discuss in depth the principles and concepts embedded in the solution.

Both, the traditional "hand-written" approach and the "software-based" approach to solve the problem are presented below in Tables 1 and 2, respectively, for examination and discussion. Figures representing variables used in the solution, as well as, the free body diagrams are also shown. These figures, however, are excluded from the discussion since they are common in both approaches.

The reader is now directed to carefully examine Table 1. In this table, the familiar conventional steps of a traditional procedure to solve physics problems are presented.

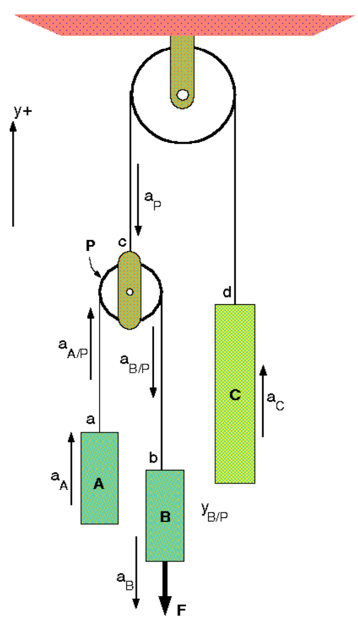


Figure 2.- Variables for system analysis

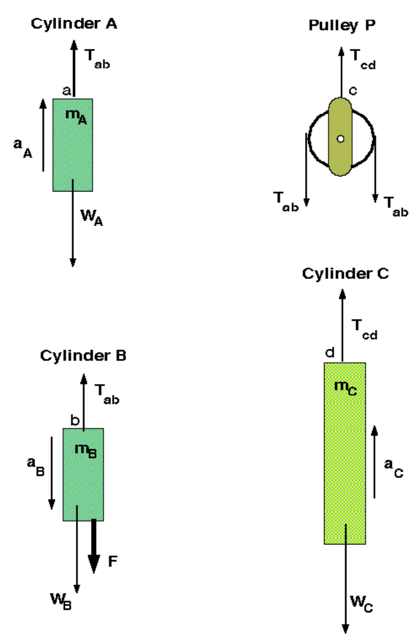


Figure 3.- Free body diagrams

TABLE 1
Conventional solution and computation procedure for motion-related problem

Organize Data

$m_A = m_B = 5.00kg$

$m_C = 10.0kg$

$v_o = 0\ m/s; \quad s = 2.50m; \quad t = 2.00s$

Describe the **relative motion** *of the elements of the system (refer to figure)*

$\mathbf{a_A} = \mathbf{a_P} + \mathbf{a_{A/P}}$ (vector form), or $a_A = -a_P + a_{A/P}$ (scalar form) (1)

$\mathbf{a_B} = \mathbf{a_P} + \mathbf{a_{B/P}}$ (vector form), or $-a_B = -a_P - a_{B/P}$ (scalar form) (2)

notice that $a_C = a_P$, *and* $a_{A/P} = a_{B/P}$ (3)

Compute the acceleration a_B *based on relationships learned on* **kinematics of particles**

$$s = \frac{a_B t^2}{2} \quad \Rightarrow a_B = \frac{2s}{t^2} = \frac{2 \times 2.50m}{2.00^2 s^2} = 1.25m/s^2$$

Since the masses of the pulleys are asumed negligible, **Newton's Second Law** $\sum \mathbf{F} = \mathbf{ma}$ *applied to pulley P indicates that (see figure 3):*

$T_{cd} = 2T_{ab}$

Compute the **weight** *of each cylinder based on their* **mass**

$W_A = m_A g = 5.00kg \times 9.80m/s^2 = 49.0N = W_B$

$W_C = m_B g = 10.0kg \times 9.80m/s^2 = 98.0N$

Now apply Newton's Second Law to each cylinder

Cylinder A

$-W_A + T_{ab} = m_A a_A, \quad \Rightarrow -49.0 + T_{ab} = 5.00a_A$ (4)

Cylinder B

$-W_B + T_{ab} - F = m_B(-a_B) = -5kg \times 1.25m/s^2, \quad \Rightarrow -49.0 + T_{ab} - F = -6.26$ (5)

Cylinder C

$-W_C + T_{cd} = m_C a_C$, *and because* $T_{cd} = 2T_{ab}$, $\Rightarrow -98.0 + 2T_{ab} = 10.0a_C$ (6)

There are 6 algebraic equations – (1) thorugh (6) – and 6 unknowns : $T_{ab}, F, a_A, a_C, a_{A/P}$, *and* $a_{B/P}$, *therefore, the mathematical manipulation of the* **simultaneous system of equations** *will facilitate the solution to this problem.*

TABLE 1
(cont.)…….

Manipulate equations (algebraic procedure),

From equations (4) *and* (6) *we determine that* $a_A = a_C = a_P$
Substitute this into equations (1) *and* (2) *,use equation* (3) *and simplify,*

$$a_A = -a_C + a_{A/P} = -a_A + a_{B/P}, \qquad \Rightarrow 2a_A = a_{B/P} \qquad (7)$$

$$-a_B = -a_C - a_{B/P} = -1.25 = -a_A - a_{B/P}, \qquad \Rightarrow a_A = 1.25 - a_{B/P} \qquad (8)$$

Add (7) *and* (8) *to eliminate* $a_{B/P}$*, and calcualte* a_A

$$3a_A = 1.25, \quad \Rightarrow a_A = \frac{1.25}{3} = 0.420 m/s^2 = a_C$$

Substitute into equation (4) *and find the tension* T_{ab}

$$T_{ab} = 5.00a_A + 49.0 = 5.00kg \times 0.420 m/s^2 + 49.0N = 51.1N$$

Calculate the force applied on cylinder B from equation (5)

$$F = 6.26N - 49.0N + T_{ab} = 6.26N - 49.0N + 51.1N = 8.36N$$

Calculate the tension T_{cd} *in rope* cd *as requested by the problem.*

$$T_{cd} = 2T_{ab} = 2 \times 51.1N = 102N$$

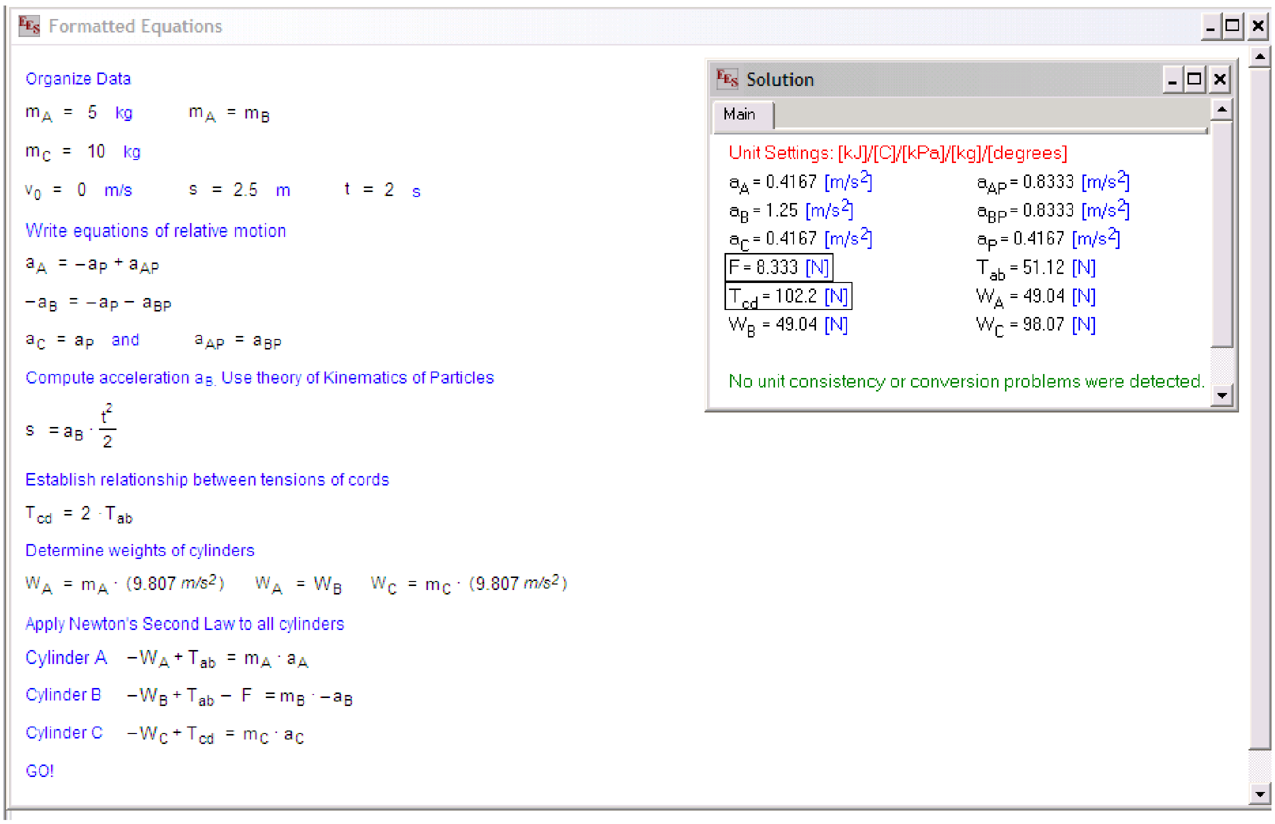
Find the relative accelerations $a_{A/p}$ *and* $a_{B/p}$*. From equation* (7)

$$a_{B/P} = 2a_A = 2 \times 0.420 m/s^2 = 0.840 m/s^2 = a_{A/P}$$

Answers :
$\mathbf{T_{cd} = 102N}$
$\mathbf{F = 8.36N}$

In contrast, the reader is directed now to examine the "software" solution developed with the help of EES in Table 2.

TABLE 2
EES solution for the motion-related illustrative problem



The simplicity, speed and convenience of using software to solve the problem are readily apparent from the examination of these two tables. A substantial part of the "hand-written" solution is devoted to the "manipulation" of a system of 6 equations and 6 unknowns to arrive at an answer. This gives the appearance of a "multi-step brute-force use-of-formula" problem. It also represents considerable time, and mathematical burden (numerical calculations, substitution of variables, elimination, etc.) which detract students from learning and understanding in depth the subject matter and conceptual context behind the problem.

On the other hand, in the "software-based" the manipulative burden is completely eliminated. Once the principles and concepts have been correctly applied in a structured manner, the software takes charge of time-consuming algebraic procedures, numerical calculations and related simplifications that lead to the answers. Therefore, time that would have been lost in the intricacies of algebraic manipulation and computations can now be used to focus on understanding better the concepts and principles behind the problem. In the example above, these few but fundamental aspects are; *relative motion, Newton's Second Law, kinematics of particles, weight, mass, and the significance of the assumptions* (boldfaced in the "conventional" solution). The more time is devoted to understand these aspects with the proper depth, the clearer the structure of the solution. Correspondingly, the clarity and correctness of the mathematical structure of the solution are the natural consequence of the comprehension of the subject matter.

When using the software, therefore, the meaning and significance of the equations, symbols and assumptions that communicate the nature of the problem become the focus of the learning process. Mathematical burden is of no concern and students are encouraged to channel their effort and time to develop a better sense of the underlying science and a deeper insight of the subject matter.

The next illustrative example relates to the familiar concept of energy. Energy is one of the most important concepts in science and technology. A firm grasp of this concept is essential in all engineering disciplines and physics courses offer innumerable opportunities for developing proper insight of this important concept early in the curriculum. Energy is quite often defined as the capacity to do work. Work, however, is only one of the forms of the energy, and the absence of the capacity to do work does not necessarily imply the absence of energy.

Finding the correct semantics to define energy proves to be complicated. In contrast, it is relatively easy to identify the numerous forms of energy in the cosmos. It is also easy to observe that energy is constantly being transformed naturally or artificially by human-made systems. Moreover, there are a *quality* and an *order* associated with the concept of energy and its use by humans. Obviously, to define and quantify *quality* and *order* one needs references and quantifying tools. These references and tools can be conceptually understood based on a clear comprehension of physical quantities such as work, heat, temperature, efficiency, irreversibility and entropy, all these, subjects of fundamental importance for all engineering disciplines.

When teaching or learning about these concepts in physics courses, it is common to use illustrative examples or problems to convey the ideas. However, the inherent algebraic manipulation and numerical calculations of solution processes can seriously distract and/or impair students from capturing the very essence of simple but important concepts readily applicable to every day life. Energy is one of them.

Consider, for example, the idea of *conservation of energy*. Conservation of energy is a technique aiming to use the energy wisely and appeals to the human concept of stewardship of our planet. Humans use energy all the time and everywhere. In doing so, however, the quality of the energy is degraded. This quality is embodied in the concept of entropy. Entropy is a real physical quantity and its magnitude can be understood as a quantification of human wisdom when using energy. In down-to-earth terms we may state that the higher the entropy generation in a process involving use of energy, the lower the wisdom. The following simple problem illustrates all these ideas and more.

Consider a simple electric shower as shown in the figure 4. The incoming water needs to be *heated from 15.0°C to 45.0°C and the user of the shower consumes 8.00 L/min. How much electric energy is consumed if the user takes 10.0 min to take a shower? What is the entropy generation in this process? Now, in an effort to conserve energy, the owner installs an energy-recovering unit that recovers heat from the draining water as shown in figure 5. The heat recovered is used to preheat the incoming cold water of the shower. Assume the draining water enters the heat-recovering system at 40.0°C and that the unit is only 50% effective (it can only recover half of the maximum possible recoverable energy in the draining water). How much electric energy is now consumed by the user during the 10.0 min shower? Is the entropy generation less in this case?*

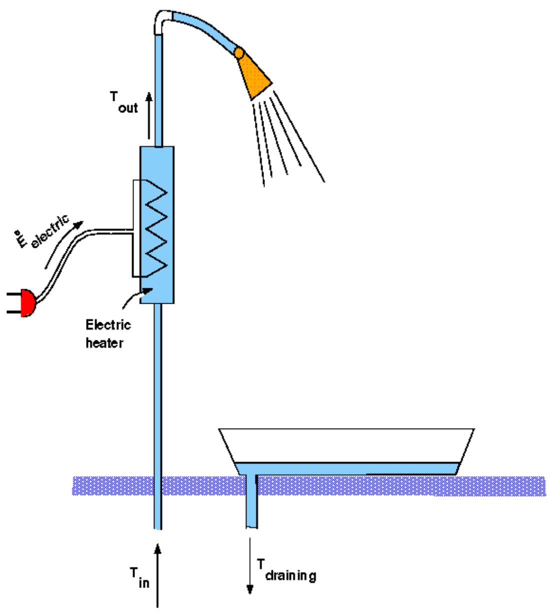


Figure 4.- Shower without energy-recovery

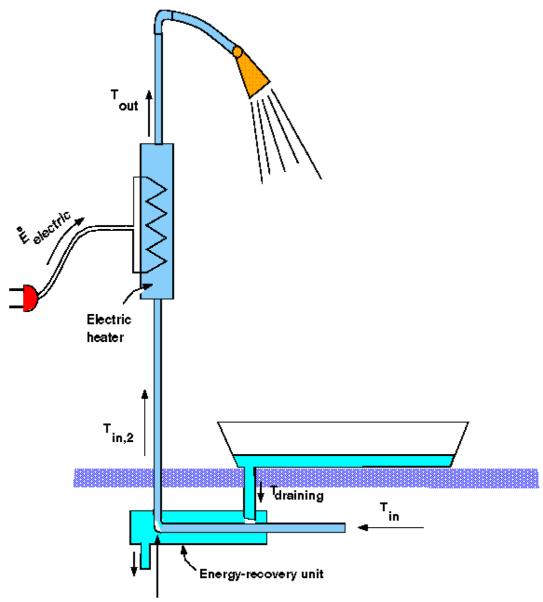


Figure 5.- Shower with energy-recovery

As for the previous case, the conventional solution to this problem is presented in Table 3. This table includes boldfaced aspects that students need to comprehend in order to develop a meaningful solution. Central ideas in this case are the *First Law of Thermodynamics* and *the principle of Entropy generation.* Other words involved are *specific heat, absolute temperature, mass flow rate, density and effectiveness.*

If the focus is on numerical computation, instead of the genuine understanding of these ideas, the essence of the scientific foundation behind human needs and the technological opportunities to satisfy those needs is missed. The value and effectiveness of good learning in engineering disciplines heavily relies on time spent to achieve good insight of the concepts. Time availability for this purpose can be increased dramatically in introductory physics, if the mathematical and computational burden of solving problems is left to the computers to handle, as illustrated in the EES solution of Table 4.

TABLE 3
Conventional method to solve illustrative problem about the energy-related concepts

Solution

CASE 1: *No energy recovery unit* :

Calculate the electric energy consumed by applying the **First Law of Thermodynamics** *to the heating process of the water. Assume* **density** *of water to be* $1.00\times10^3 kg/m^3$.

The **mass flow rate** *of water is found from*

$$\dot{m} = \dot{V}\rho_W = (8.00L/\min)\times\left(\frac{10^{-3}m^3/L}{60.0s/\min}\right)\times1.00\times10^3 kg/m^3 = 0.1\overline{3}kg/s$$

$$\dot{E}_{electric,1} = \dot{m}C_{water}(T_{out}-T_{in}) = 0.1\overline{3}k/s\times4.18kJ/kg.C\times(45.0-15.0)^{\circ}C = 16.7kW$$

$$E_{electric,1} = time_{shower}.\dot{E}_{electric,1} = 10.0\min\times(60.0s/\min)\times16.7kW = 1.00\times10^4 kJ$$

Find **absolute temperatures** *of incoming and outgoing heated water*,

$$T_1 = 15.0+273 = 288K; \qquad T_2 = 45.0+273 = 318K$$

Calculate the **entropy generated** *in this process using*,

$\dot{S} = \dot{m}\int_{T_1}^{T_2}\frac{C(T)}{T}dT,$ *The* **specific heat** $C(T)$ *is esentially constant for liquid water under the conditions specified by the problem. Therefore*,

$$\dot{S}_{generated,1} = 0.1\overline{3}kg/s\times\int_{288}^{318}\frac{4.18}{T}dT = 0.1\overline{3}kg/s\times4.18kJ/kg.K\times\ln T\Big|_{T_1}^{T_2}$$

$$= 0.560kJ/s.K\times\ln\frac{318}{288} = 0.0553\ kJ/s.K$$

$$S_{generated,1} = time_{shower}\dot{S}_{generated,1} = 10.0\min\times(60.0s/\min)\times0.0553kJ/s.K = 33.2kJ/K$$

TABLE 3
(cont.)……

CASE 2 *With energy – recovery unit*

Find **energy recovered** (*this represents energy saved*). **Effectiveness** *given is* $\varepsilon = 0.5$

$$\dot{E}_{saved} = \varepsilon \dot{m} C_{water}(T_{draining} - T_{in})$$
$$= 0.500 \times 0.1\overline{3} kg/s \times 4.18 kJ/kg.C \times (40.0 - 15.0)^{o}C = 6.97 kJ/s$$
$$E_{saved} = time_{shower} \times \dot{E}_{saved} = 10.0 \min \times (60.0 s/\min) \times 6.97 kJ/s = 4.18 \times 10^{3} kJ$$

Calculate consumption of electric energy when using energy – recovery unit

$$E_{electric,2} = E_{electric,1} - E_{saved} = 1.00 \times 10^{4} kJ - 4.18 \times 10^{3} kJ = 5.86 \times 10^{3} kJ$$

Calculate the entropy generation. We first need to determine the temperature achieved by the incoming water when heated by the recovery unit.

Apply **First Law of Thermodynamics** *in heat – recovery process*

$$\dot{E}_{saved} = \dot{m} C_{water}(T_{in2} - T_{in}) \quad solve\ for\ T_{in2}$$
$$T_{in2} = T_{in} + \frac{\dot{E}_{saved}}{\dot{m} C_{water}} = 15.0^{o}C + \frac{6.79 kJ/s}{0.1\overline{3} kg/s \times 4.18 kJ/kg.C} = 27.3^{o}C$$

Therefore, the absolute temperatures are now

$$T_1 = 27.3 + 273 = 300K \quad and \quad T_2 = 318K$$

Calculate the entropy generation.

$$\dot{S}_{generation,2} = \dot{m} C \ln\frac{T_2}{T_1} = 0.1\overline{3} \times 4.18 kJ/kg.K \times \ln\frac{318}{300} = 0.0320 kJ/s.K$$
$$S_{generation,2} = time_{shower} \dot{S}_{generation,2} = 6.00 \times 10^{2} s \times 0.0320 kJ/s.K = 19.0 kJ/K$$

Which is about 43.0% *less than the entropy generated without energy recovery unit.*

Answers :

$\mathbf{E_{electric,1} = 1.00 \times 10^{4} kJ}$, $\mathbf{S_{generation,1} = 33.2 kJ/K}$

$\mathbf{E_{electric,2} = 5860 kJ}$, $\mathbf{S_{generation,2} = 19.0 kJ/K}$

"Proceedings of the 2003 American Society for Engineering Education Annual Conference & Exposition

TABLE 4
EES solution of energy-related illustrative problem

Formatted Equations

Solution

CASE1- No energy recovery

Calculate the mass flow rate and the electric energy consumed

$\dot{m} = \dot{V} \cdot \rho_{water}$

Apply the First Law of Thermodynamics $\dot{E}_{electric,1} = \dot{m} \cdot C_{water} \cdot (T_{out} - T_{in})$

$E_{electric,1} = \dot{E}_{electric,1} \cdot time_{shower}$

$T_1 = T_{in} + 273 \quad T_2 = T_{out} + 273$

Calculate entropy generation

$$\dot{S}_{generated,1} = \dot{m} \cdot \int_{T_1}^{T_2} \left[\frac{C}{T}\right] dT$$

$S_{generated,1} = \dot{S}_{generated,1} \cdot time_{shower}$

CASE 2- Energy recovery

Find energy saved by using recovery system and the new reduced electric energy consumed

$\dot{E}_{saved} = \varepsilon \cdot \dot{m} \cdot C_{water} \cdot (T_{draining} - T_{in})$

$E_{saved} = \dot{E}_{saved} \cdot time_{shower}$

$E_{electric,2} = E_{electric,1} - E_{saved}$

Calculate the temperature of water obtained by using recovery unit

Apply First Law of Thermodynamics $\dot{E}_{saved} = \dot{m} \cdot C_{water} \cdot (T_{in,2} - T_{in})$

$T2_1 = T_{in,2} + 273 \quad T2_2 = T_2$

Entropy generation

$$\dot{S}_{generated,2} = \dot{m} \cdot \int_{T2_1}^{T2_2} \left[\frac{C}{T2}\right] dT2$$

$S_{generated,2} = \dot{S}_{generated,2} \cdot time_{shower}$ GO!

Solution

Main

Unit Settings: [kJ]/[C]/[kPa]/[kg]/[degrees]

$E_{electric,1}$ = **10041** [kJ] $E_{electric,2}$ = **5857** [kJ]

$S_{generated,1}$ = **33.17** [kJ/K] $S_{generated,2}$ = **18.95** [kJ/K]

No unit consistency or conversion problems were detected.

Another illustrative example is presented in Appendix B. This problem is relative to electricity, another fundamental area of introductory science for engineering students. The reader is directed to consider and experience, if possible, the time and burden behind the algebraic procedures involved in the "traditional" solution in contrast to the simplicity of the software-based solution..

Discussion.

Contrary to the original author's belief, the application of the computer software-based approach to teaching physics resulted in significant educational gains. In fact, the study was initiated with apprehension and doubt on the part of the author in regard to the real benefits of this pedagogy.

However, a careful evaluation of students' performance in tests, exams and homework showed substantially higher level of clarity, organization, and correctness, as compared to similar groups taught in a more traditional fashion. This evidence suggests that the computational power of the computer software helps engineering students considerably to gain a deeper understanding of the fundamental concepts and principles of fundamental science. The familiar student's struggle with manipulation of formulas and the typical time-consuming computational burden associated with solving exercises, exams or homework effectively disappear. As a result, ample time is left for instructor to cover more subjects and concepts in depth, and for students to focus on deeper understanding of the underlying science of the subject matter.

Far from being a distraction and an impediment for academic rigor, the software-based approach to teaching and learning introductory undergraduate physics makes the educational experience more enjoyable, dynamic and effective. Student participation and interest increase dramatically during class lectures. Because time dedicated to mathematical manipulation and computation is no longer an educational constraint, students become more attentive and focused on the discussion and comprehension of the subject matter instead of "cookbook" application of formulas. As much as 50% additional class time for subject discussion and comprehension can be achieved with the inclusion of computer software as a teaching tool in the classroom. This additional time provides exceptional opportunity for in-depth discussion about the concepts and principles covered in introductory physics rendering instructor's and student's efforts effective to the educational objectives of the scientific foundation of engineering curricula. Students no longer find physics to be a roadblock of their studies, but the indispensable, reliable and firm scaffold that prepares them to exercise the engineering profession with confidence and efficacy.

Apart from computer infrastructure availability, the inclusion of computer-based instruction in physics courses needs to be recognized as an innovative pedagogical approach of the present, and the unquestionable teaching method of the future.

Conclusion.

Physics is the subject that provides scientific foundation to a majority of engineering disciplines. Solid and reliable scientific foundation can be provided to engineering students taking introductory physics by utilizing a pedagogy that focuses on genuine and deep comprehension of the concepts and principles of science instead of a "cookbook" approach that stresses on formula manipulation and numerical calculation. Time and effort spent on "recipe" techniques to solve problems in physics can be easily redirected to achieving good insight of concepts and principles by incorporating the use of computer software in the teaching and learning processes. Dramatic educational gains can be accomplished in regard to depth and coverage of subjects in physics courses if time spent in manipulation of formulas and numerical calculations is better used to strengthen the conceptual foundation of engineering students. Using computer software to eliminate tedious manipulative and computational burden of physics problems allows instructors to foster an environment that helps students to master the ideas of science more effectively and triggers interest and enthusiasm for cognitive skill. A preliminary evaluation was performed by the author of the academic performance of a group of engineering students enrolled in introductory physics at Northeastern University. The software EES was extensively used to impart instruction of scientific subjects, develop exercises in class, and for the testing of student's knowledge and skills. The evaluation suggests that the computer software was instrumental for students to focus on conceptual insight of the underlying science of engineering and for demonstrating a clear comprehension of the fundamental concepts and principles imparted in class.

References.

[1] Bork, A., 1981 "Learning with computers" Digital Press. Bedford. MA
[2] Hecht, E. 1998. "Physics" Brooks/Cole Publishing Co. ITP. Albany, NY
[3] Hewitt, P. 1998. "Conceptual Physics" Addison-Wesley. Reading. MA.
[4] Klein, S., Alvarado, F.2002. "Engineering Equation Solver" McGraw-Hill. New York, NY.
[5] Lightman, A. 2000 "Great Ideas in Physics" McGraw-Hill. New York.
[6]Lopez,G. 2002 "Cutting Computation time and mastering the Underlying science of Introductory Thermodynamics" ASME-IMECE Proceedings. New Orleas, LA.
[8] Ohanian, H., 1989 "Physics" Rensselaer Polytechnic Institute. W.W. Norton, NY.
[9] Price, R., 1991 "Computer-aided Instruction" Brooks Cole, Pacific Grove, CA.
[10] Purcell, E. 1985 'Electricity and Magnetism, Berkeley Physics Course", McGraw-Hill, New York, NY.
[11] Salem,K., 1994, "The New Gravity", Salem Books, Johnstown, PA.
[12] Serway, R. 1992. "Physics for Scientists and Engineers" Saunders Golden Sunbusrt Series. Saunders College Publishing. Philadelphia, PA.

BIBLIOGRAPHICAL INFORMATION.

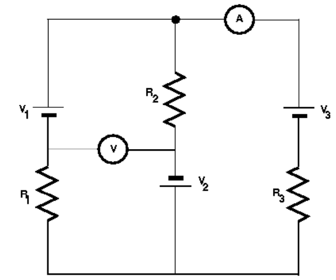
Guido W. Lopez.

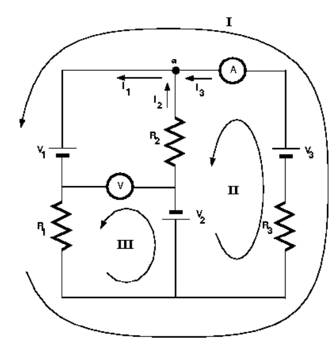
Guido Lopez is a Faculty member of the School of Engineering Technology at Northeastern University, Boston. He teaches Introductory Physics for Engineers, Thermofluids Science, Instrumentation, Laboratory Experimentation, Technology and Design. Before joining NU's faculty, he served as Department Head of the Engineering Math and Science Division at Daniel Webster College, Nashua, NH. He has taught engineering and science subjects at the National Polytechnic School in Quito, Daniel Webster College in New Hampshire, The Lowell Institute of Technology at Northeastern University, and the Wentworth Institute of Technology in Boston. He has performed applied research at the NASA John Glenn Research Center, Cleveland on advanced solar dynamic systems for power generation for the international space station alpha. Lopez received his M.S. degree and, Ph.D. degree in engineering science and Thermofluids science from Northeastern University.

APPENDIX A
A comparison case for a physics problem related to the area of electricity

Consider the following typical problem and compare the tabulated solutions. The benefits of using software for mathematical manipulation and time savings are evident. A short reference of important concepts and principles behind the problem is presented at the end.

In the circuit shown in the figure, V_1*=5.00 V,* V_2*=15.0 V,* V_3*=10.0 V,* R_1*=6.00Ω,* R_2*=3.00Ω and* R_3*=4.00Ω. What are the voltmeter and ammeter readings? Assume these devices to be ideal.*





Conventional Solution

Data

$V_1 = 5.00\,V,\quad V_2 = 15.0\,V,\quad V_3 = 10.0\,V$

$R_1 = 6.00\Omega,\quad R_2 = 3.00\Omega,\quad R_3 = 4.00\Omega,$

Apply Kirchhoff's rules:

Loop I

$-V_1 - R_1 I_1 - R_3 I_3 + V_3 = 0 \qquad (1)$

Loop II

$V_2 - R_3 I_3 + V_3 + R_2 I_2 = 0 \qquad (2)$

Loop III

$V - R_1 I_1 - V_2 = 0 \qquad (3)$

Node a

$I_1 = I_2 + I_3 \qquad (4)$

Substitute values, manipulate the system of simultaneous equations, and perform numerical calculations.

$-5.00 - 6.00 I_1 - 4.00 I_3 + 10.0 = 0, \quad \Rightarrow 6.00 I_1 + 4.00 I_3 = 5.00 \qquad (5)$

$15.0 - 4.00 I_3 + 10.0 + 3.00 I_2 = 0, \quad \Rightarrow 3.00 I_2 - 4.00 I_3 = -25.0 \qquad (6)$

$V - 6.00 I_1 - 15.0 = 0, \quad \Rightarrow V - 6.00 I_1 = 15.0 \qquad (7)$

Substitute (4) *into* (5) $\quad \Rightarrow 6.00(I_2 + I_3) + 4.00 I_3 = 5.00,$ *solve for* I_2

$$I_2 = \frac{5.00 - 4.00 I_3}{7.00} - I_3 = \frac{5.00}{7.00} - \frac{11.0}{7.00} I_3 \qquad \textit{substitute into } (6)$$

$$3.00\left(\frac{5.00}{7.00} - \frac{11.00}{7.00} I_3\right) - 4.00 I_3 = -25.0 = \frac{15.0}{7.00} - \frac{33.0}{7.00} I_3 - 4.00 I_3 = \frac{15.0}{7.00} - \frac{61.0}{7.00} I_3$$

Solving for $I_3 = 3.10\,A$

Substitue into (5) *and find* $I_1 \quad \Rightarrow 6.00 I_1 + 4.00 \times 3.10 = 5.00, \quad \Rightarrow I_1 = -1.20\,A$

Substitute into (7) *and find* V

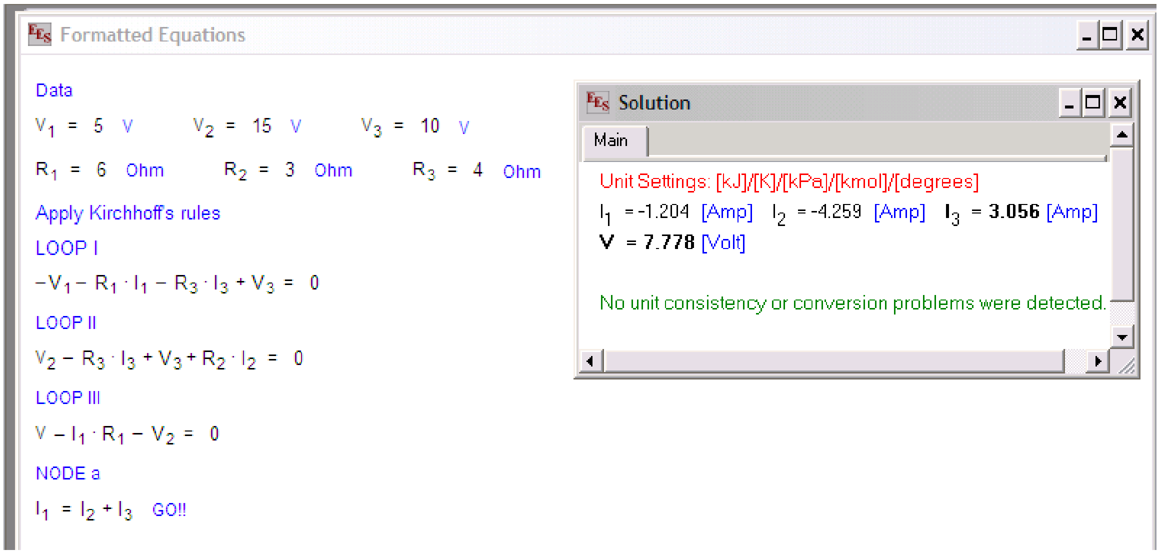
$V - 6.00 \times (-1.20) = 15.0 \quad \Rightarrow V = 7.80V$

Answers

$\mathbf{I_3 = 3.10A}$

$\mathbf{V = 7.80V}$

EES Solution



Rather than spending time solving a system of algebraic equations by hand, which the software can do very fast, instructor and students use this time to understand in depth important aspects of science, such as, ***electromotive force, flow of charge, conservation of charge, electric resistance and resistivity, Ohm's Law, Kirchhoff's rules***, etc.

If these aspects are correctly understood, students will be able to structure the solution correctly by establishing the four equations indicated in the table above (Loops I,II and II, and Node a). Unlike the "conventional solution", the algebraic manipulation and calculations beyond this point are left to the computer in the "software" approach. This represents considerable time savings.