A Multidisciplinary Engineering Computation Module for Introductory Courses in Engineering Technology

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Abstract
Topics selected for introductory courses in engineering technology and in engineering should help students decide if they want to pursue the degree and, if so, to prepare them for work in their later courses and in their careers. The topics should be applicable in different areas of technology. The author has found that a module on computations using rates and capacities meets these criteria and is a useful addition to a first year course. This paper discusses this module and describes the author's experiences in teaching with this material.

Introduction

Introductory courses in engineering technology and engineering often include basic engineering computation work along with other topics. This is reflected in textbooks designed for these courses.[1,2,3,4] This is traditional engineering calculation work, and requires only paper, a pencil or pen, and simple calculator. The material does not require students to use computers or even the advanced features of a graphing calculator. The computation work must be at a mathematical level appropriate for new students. It should reflect practical problems and should give students a sense of the application of mathematical tools in technological problem solving. Since these courses are designed to serve students from different areas of technology, the course material should be applicable to all disciplines. The computational work should have utility in class design projects, in later coursework, and in the student's career.

In engineering computations, there are many applications of numerical information in the general forms of rates and capacities. Examples include flow rates in pumping and in ductwork, electrical system charging rates, and production rates for manufacturing or chemical plants, while examples of capacities or densities include values such as the heating value of a fuel. These numbers appear in practical problems, and homework problems can be designed to mimic design problems. Practical applications of rate and capacity information can be found in all engineering disciplines.

The use of this sort of information can be generalized. Through the generalized form, a technique useful across engineering disciplines can be taught to students. One must understand the meaning of the value, relate this to a mathematical expression, and solve for the desired unknown. This understanding may come from intuition, a formal definition, or from examination of the units. With experience, using this type of information becomes a straightforward task. Often, it is not straightforward for new students. Exposing student to this sort of problem helps to prepare them for other courses, projects, and for employment.

For several years, the author has included an engineering computation module based on rates and capacities in an introductory course for engineering technology students. The topic is multidisciplinary, reflects real problems, and helps to prepare students for later courses and for practical work. This paper will discuss his experience with the topic, and will describe how this can be a beneficial addition to an introductory course.

Introductory Courses and Calculations

Introductory courses have many goals. Students should finish an introductory course with a better idea of whether or not a degree – and a career – in engineering and technology suits their talents and interests. They should finish the course with a vision of what work in this field will require of them, and, hopefully, with the realization that they can do the work, and that the work will be interesting. The course is also the first step in preparing the students for employment.

Current ABET criteria for both engineering technology and engineering programs stress program outcomes that prepare students for employment. Problem solving abilities appear on both lists of program outcomes.[5,6] The concept of an introductory course for majors in technology is not new, and neither are the goals of preparing students for the rest of their degree program and for employment. A listing of aims for an engineering problems course dating from 1937 (presumably carried over from earlier editions) includes much that is applicable today in preparing students to meet the needs of employers. This listing includes encouraging students "to learn to think for themselves," develop "a sense of judgment," and to "coach … in direct and systematic ways of thinking."[7] These attributes fit preparation for the workplace and problem solving.

Textbooks for introductory courses often include material on basic engineering computation. As presented, this material is focused on calculations and on teaching general problem solving skills. This material can be used to address other goals of the course as well, such as giving students a better understanding of the work that will be required of them in practice.

The texts include a review of basic math for engineering applications. Following this, there is usually a discussion of measures and units, including the conversion of units. Once this topic has been covered, the instructor should select topics that will build on this material in a way that is, hopefully, interesting to the students. Some texts do this with topics from basic engineering analysis courses. This lets an instructor teach to their strengths in their own discipline. However, an introductory course is designed to serve students in all majors, and, ideally, topics chosen should be useful in all areas.

Whatever topics are chosen, the work must be at a mathematical level suitable for the students. For engineering technology students, the baseline assumption has been that college algebra is the appropriate starting point for college level math courses. While many students may need remedial courses in math, it is reasonable to assume that new students can be expected to use formulas and can be taught to perform basic algebraic manipulations to find an unknown value.

For over ten years, the author has taught an introductory course for new students. This is a required course in our B.S. degree program in engineering technology, and is expected to be the first course that the students take in the major. The author follows the common pattern of starting with a discussion of measures and units, and then follows with other calculation topics. In a previous paper, the author described his experience with a module focusing on work, power, and energy[8]. The course also includes a module based on the topic of rates and capacities, which is presented in this paper.

Rates and Capacities

One can find examples of rates and capacities in all areas of engineering and technology. They can be generalized as follows. A rate can be written as

Rate = Something / Time.

This can be as straightforward as speed (= distance / time). It can also be the discharge rate of a pump in gallons per minute, the charging rate for a battery (= energy stored / time), or production numbers for a manufacturing line (number of units produced / day, or week, or month, etc).

Likewise, a capacity (or density) can be written as

Capacity = Quantity of Some Characteristic / Quantity of Something.

The quantity of something may be mass, volume, item or product, etc.

The most familiar example of this type of information is the definition of density as mass (quantity of some characteristic) per unit volume (quantity of something). It can also be the capacity of a storage battery or a capacitor, where the quantity of some characteristic is the amount of energy and the quantity of something is either the mass or the volume. It can also be the heating value of a fuel, i.e., heat released per unit of fuel (kJ/kg, BTU/lb, BTU/gal, etc).

Often, students have had some experience with a few examples of rates and capacities. Prior to college, most students should have been exposed to simple problems relating the speed of a car to distance traveled or time required to cover a set distance. Students who have taken a physical science course should be familiar with density. In their education and in practice, they will be faced with computations that initially appear to be very different. If they can recognize that these new problems are similar in form to problems that they already know how to solve, they are more likely to be successful in solving the new problems. While the new situation may appear to be very different, the ability to recognize a general form will help them to see how to use the given information and solve the new problem. The ability to recognize and use information in the form of rates and capacities is a skill that will be of value to students throughout their academic and professional careers.

The general pattern to solving these types of problems is as follows. The student must

1) Read the information carefully,
2) Recognize the type of information and link this with the general form,
3) Set up the specific problem using the correct form, and
4) Find the desired results.

In doing this, the student must follow a rational approach, recognize the pertinent information, and pay attention to the units. Checking of units is an important part of this process, and should be stressed in teaching this material.

The recommended process is for the student to write out an equation in words. For example, a heating value problem can be written as

Heating Value = Heat Released / Volume of Fuel Burned.

This step helps the student to visualize the meaning of the information and to see the relationship needed for calculations. If a student recognizes the meaning of the value, the math necessary to solve practical problems is straightforward. Ideally, the student recognizes the form from the name, the units, or both. The student then needs to identify the given information and replace names with values, taking care to ensure that the units are consistent. With that step completed, the calculation operation should be clearly visible.

In the author's experience, the key issues are 1) for students to recognize the meaning of the information and 2) to see how to use the information. While this may appear straightforward, it is not always clear to the students.

In addition to teaching students the direct use of rates and capacities, this topic gives room to explore other issues in engineering calculations. This topic can be used to give students some experience with ambiguous information, and help them learn how to make full use of the available information. There are cases where a single value of a rate or capacity may not be available, or even appropriate, and instead minimum and maximum values will be given in specifications. The heating value is a good example of this situation. Also, many numbers are based on physical measurements, and there would be variation between values obtained with different test specimens. Both cases can be used to show students that numbers are not always absolute physical constants defined by some aspect of nature to an indefinite number of decimal places. Rather, many numbers they will encounter will be set (or set as a range) by definition, and the actual value should be somewhere within this range. One can take this farther to point out that material as supplied often must be tested to ensure that the measured value for this batch of material does fall within the specified limits.

Use of Rates and Capacities as a Course Topic

During his first summer as an intern in a consulting firm, the author remembers one of the designers taking the time to explain the key formula for HVAC duct design. This gives the flow rate of air in cubic feet per minute as:

CFM = Flow Rate (in ft/min) times Duct Cross Section Area (in sq ft)

This made an impression that has stayed with the author. For a mechanical engineering student who had completed his second year in a research oriented engineering school, the level of math was simple. There was no evidence of calculus or of differential equations. The math and science requirements of the engineering curriculum aside, one did not need to use calculus or differential equations directly to solve the practical problems of HVAC system design. For this application, the problem could be reduced to a simple formula. To use this, one did have to be careful to put information in the correct units, as ductwork dimensions were often given in inches.

It also made an impression that the experienced designer thought it necessary to explain this to an engineering student. The author assumes that experience had taught this designer that someone did need to explain the equation for flow in CFM to new interns. The author's experience with students has been that students do need help learning how to recognize and use rates, such as the air flow rate in CFM, and capacities in engineering calculations.

The goal of using this material is to do for the students in general what that designer attempted to do for the author with the specific problem of sizing ductwork: show them how to do a basic form of engineering calculation.

The experienced designer described the volume flow rate of air in a duct as a formula. This is a practical example of a rate problem. While it is given as a formula, it is not necessary to treat this subject as the teaching of specific formulas. Rather, this can be approached as a process of 1) recognizing the type of information and 2) fitting it to the general form shown above. Recognition may come from the definition of the value or from looking at the units. Using these general forms, students develop a formula for the value, and can use that formula to find the desired results.

Teaching this subject as a process of recognizing a general form and, from that form, developing the mathematical relationship teaches problem solving skills. Students are required to think through the problem on their own, rather than only being required either to look up or to memorize a formula for a specific application. Students learn to follow a systematic process, and follow the same systematic process for similar problems from different disciplines.

Sample Problems

The following problems are taken from homework and examination questions on this topic. The problems range from the most straightforward to problems requiring students to use ranges of values and to make judgments.

In some cases, the units show clearly how to use the information. A pumping problem may state that a pump moves water at 350 GPM. If students recognize this number in gallons per minute as a rate, they can then look at it in the general form for a rate, where the quantity of something is volume of water in gallons and time is in minutes. With this general form, they can use this rate value with a given number of gallons to find the time, or a given period of time to find the volume in gallons.

In some problems, the students must read the units from the given information. For example, a problem statement may give a production line's output as an average number of products produced in one week. Students will need to interpret this as a rate in products produced per week.

In all cases, students must pay attention to the units. Realistic problems can be structured to require unit conversions, linking this material to earlier topics on units.

1. A pump pulls water from an irrigation ditch at a volume flow rate of 20 gallons per min (gal/min). How long will it take for this pump to fill a 5,000 gallon tank truck? Fresh water has *a weight density of 62.4 pounds per cubic foot (lb/ft^3). When filled, what are the volume in cubic feet and the weight in pounds of the water in the tank?*

2. Two manufacturing production lines have been set up to produce the same product. In one day, the old line can produce 250 products, and the new line can produce up to 400 products. Given that a standard month of production consists of 4 weeks with 5 working days each week, what is the maximum monthly output of this product without resorting to overtime production?

3. An electronic device operates at 9 volts with a current draw of 30 mA (milli amperes). When fully charged, an Energizer rechargeable nickel metal hydride (NiMH) 9 volt battery is rated at 150 mA·hours (data taken from the Energizer Battery web page).

a) *How long can this battery power the device before it must be recharged?*
b) *The voltage of a battery drops as the battery is discharged. For a specific application, the battery voltage drops below the acceptable level for operation at 80% discharge. Under these conditions, how long can this battery power the device before recharging?*

4. Natural gas has a heating value range of 950 - 1100 BTU/cubic foot under ideal combustion conditions at industrial standard temperature and pressure (30 inches of mercury and 60 ^oF). If a process requires a heating rate of 100,000 BTU/hr, what gas flow rate (cubic feet per minute) is required to meet this demand?

5. The pump feeding an oil-fired burner supplies No. 2 fuel oil at a volume flow rate of 5 gallons per minute. The heating oil has a (weight) density of between 6.960-7.296 lb/gal and a heating value from 137,000 to 141,000 BTU/gal.

a) *Fuel is stored in a 15,000 gallon tank. When filled to capacity, how much does the fuel in this tank weigh?*
b) *Calculate the amount of heat released in BTUs during one hour of operation.*
c) *How long will it take for the system to use all of the fuel in the 15,000 gallon storage tank? Will this tank be large enough for the system to run for two days without refilling the tank?*

It is not difficult to create problems of this type. At best, they are based on actual problems in design and operation. Information such as heating values can be found in handbooks and specification sheets. Realistic problems serve to simulate problems to be found on the job and contribute to meeting the course goals of introducing students to and preparing them for engineering practice. Also, realistic problems should be interesting to the students.

While some students are well prepared to work with this sort of problem, others are not. In the author's experience, students who have trouble 1) fail to carefully read the information and put it in the form of a calculation, 2) fail to write out and check units, and 3) fail to see in these problems a common – and rational – approach. Pushing students to follow a common procedure and to write out rates and capacities as ratios in words rather than in numbers can help. It can also help to walk students through the translation from a written problem statement to an equation, and to insist that the students write out the units throughout the calculation.

Some students state that they could solve the problems if they were given a formula. They cannot proceed unless given a specific formula for the application. The goal here is to help them develop the ability to read the formula from the information, and to see that it is not necessary to develop and memorize a separate formula for each application. This is a step in teaching the students to think for themselves, rather than to rely on someone or some source to hand them a formula. It can also be a lesson in the importance of giving attention to the units.

The more advanced problems shown require students to deal with ambiguous information. Reflecting information found in practice, a problem could be given with information in the form of a range of acceptable values. Often, students want to approach information given as a range of values by finding an average value. This approach throws away useful information about the expected range of acceptable results. Students tend to think that the final result should be a single number. By using the average for the range and getting a single number, they cannot say how far actual results may range around this midrange result. A better approach that makes the best use of the given information has students making calculations for both the upper and lower values of the range. With this, they have an upper and lower value for the result, and have not thrown away useful information about the acceptable range of values.

This can set the stage for further exercises in judgment that show the value of making calculations for the upper and lower limits of the range. If a problem is concerned with the maximum weight of a load, then one should use the upper value to find the maximum expected load. If a problem is concerned with supplying a required amount of heat, the lower heating value should be used to insure that the fuel supply would be adequate even if the fuel were at the lower acceptable limit of the heating value.

Benefits to Students of Teaching Rates and Capacities as a General Calculation Topic
The author expects that, to anyone with experience, this seems straightforward. However, it has not always proven to be easy for students. Experience with students has shown the author that many students seeking both engineering technology and engineering degrees do need help in learning how to use this type of information. As an instructor, the author would be embarrassed if (and embarrassed for) any student going into an internship – or to their first job on graduation – if the student would have difficulty dealing on their own with this sort of problem. The first goal of teaching this topic is to prepare students to do this sort of engineering calculation on the job without having to be taught this on the job.

As noted earlier, this subject can be used to teach general and systematic problem-solving methods. It can help students develop the ability to reason through a problem. Problems can be structured to require students to develop judgment. With appropriate feedback, this topic can also be used to teach (and insist on) clear documentation of calculation work. As students understand how to use the general form to develop a relationship in a specific application and that attention to units is crucial to their success, they realize that there is more to documentation than just copying a formula from a reference.

This topic is also valuable in helping students understand what math skills are likely to be expected of them on the job. For the more math-phobic students in engineering technology, this topic can be a valuable indicator that they can do the math required in many jobs. If a student is considering leaving the program because of fears that difficulty with higher level math requirements means that they will fail in the workplace, helping them to see that much in engineering calculations is at a relatively simple math level will give them confidence, and can be a factor in student retention.

For the students who are strong in math, this module can also be quite useful. One does not want to produce graduates who may excel in advanced math courses in differential equation solving techniques but cannot solve straightforward problems. Experience with common engineering calculations will help them to see that they will not always need to make use of the higher level math, and help them to develop the judgment to recognize where simple calculations are sufficient.

Finally, this topic can be used to show calculations as a means to an end. The problem may be posed such that the calculation result is used to make a decision. For example, the calculated value may be used to decide if a project is feasible, or to make design decisions. This has value in that it emphasizes the goal of making a decision, rather than just making calculations.

Further Development

To date, the author has used this material in traditional instruction. The topic is covered in lectures, and students are assigned homework to complete on their own. The necessary information is included with the problems, and students are only required to perform the calculations and make any necessary judgments. Similar problems are included in course examinations.

The next step would be to build on this skill in problems where students are required to find necessary information and to use the results in making decisions. This topic can be taught prior to assignment of a project, or as needed in a project-based course. While currently taught in individual instruction at first, use in projects would likely be part of a team effort.
The project work may require students to use the library and the Internet to find necessary information. A design project would require students to use this type of calculation to check feasibility and to make design decisions.

Conclusions

The subjects of rates and capacities can be used as the basis of a multidisciplinary engineering computation module for introductory courses in engineering and engineering technology. This module builds on topics commonly found in materials for introductory courses, and can be used to give students experience with practical computation problems. The general pattern is applicable to problems in all areas of technology. It can be used to require students to think for themselves in developing a formula for a specific application based on a general pattern for the type of problem. It can be used to help develop judgment, to demonstrate the use of mathematics in engineering, and to show that many practical problems do not push the limits of the student's mathematical abilities. Finally, this topic can be integrated with experience in searching for information and for making decisions in design projects.

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