

Strategies for Effective Teaching
A Handbook for
Teaching Assistants

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Foreword

We help our students understand engineering concepts and go beyond the knowledge level to higher levels of thinking. We help them to apply, analyze, and synthesize, to create new knowledge, and solve new problems. So, too, as teachers, we need to recognize our challenge to go beyond knowledge about effective teaching. We need to apply these strategies, analyze what works, and take action to modify or synthesize our learnings to help our students learn in a way that works for us as individuals and teams of teachers.

The learning community consists of both students and teachers. Students benefit from effective teaching and learning strategies inside and outside the classroom. This Handbook focuses on teaching strategies you can use in the classroom to foster effective learning.

Helping students learn is our challenge as teachers. Identifying effective teaching strategies, therefore, is our challenge as we both assess the effectiveness of our current teaching style and consider innovative ways to improve our teaching to match our students' learning styles.

The mission of the College of Engineering, UW-Madison, is to "create, integrate, transfer, and apply engineering knowledge." The strategic plan sets forth three broad objectives to achieve and maintain, namely,

- educational excellence
- research leadership
- technology transfer leadership.

This Handbook is one resource to assist faculty, academic staff who teach, teaching assistants, and undergraduate assistants as they strive to meet the objective of "educational excellence."

COE faculty and teaching assistants have identified the ten categories of effective teaching strategies described in this Handbook. Each description consists of an introduction, scope, examples, and conclusions which include student responses to the strategies. Our next version will contain references for each of the strategies.

You may have used these or similar strategies in your classroom with similar results. Or you may have other examples, strategies and references that you'd like to share within our teaching and learning community. Your additions and suggestions are welcome. In fact, you'll notice a distinctive feedback form as the last page of this Handbook.

With your assistance we can build a culture of continuous improvement in undergraduate and graduate teaching here at UW-Madison. By so doing, you will help facilitate an environment in which the College of Engineering becomes a learning organization. Students will benefit!

I. PRACTICAL EXAMPLES <i>Connecting Theory with Applications</i>

Students have expressed concern regarding the need for more industrial and practical examples to reinforce theory in the classroom. The use of practical examples can help you connect engineering theory with practical applications for more effective teaching and learning. The introduction of practical examples does not imply an elimination of theory, but rather an enhancement of the theory taught in the classroom. It is important to simultaneously develop a theoretical and a practical base since neither is useful without the other.

The use of practical examples in the classroom is targeted at the following two main goals:

1. Help illustrate and explain new material making the theoretical basis of the material more accessible to the students. Practical examples help students understand the new concepts being introduced.
2. Teach students how to apply their knowledge of course material to new situations that are not directly covered in class. The goal here is to show the students not only that what they are learning has practical applications, but more importantly, how to apply their understanding of the basic principles to real engineering problems.

Scope

Practical examples can be included at all levels of the engineering curriculum. When determining examples to be used for instruction it is important to make the examples as clear and straight forward as possible. The key is to make the examples as simple as possible, and to make sure that they isolate the desired principle. Whenever possible, the examples should be designed so that the students' physical senses are brought into play. Examples that are likely to be enjoyed by the students include those that require them to use their sense of sight, feeling, hearing or smell. The following guidelines should be remembered when implementing practical examples:

1. Understand the example given and be able to explain it. If you cannot provide a clear explanation to the example, the example will confuse the students more than help them.
2. Before giving a demonstration or take home assignment, carry out the assignment yourself. This will ensure that you know exactly what the students will "see". It will also help you to anticipate your students'

questions. Giving an assignment or demonstration that doesn't work is frustrating to the students and is bad for your credibility.

3. Choose examples that are relevant to the students. Examples that the students can observe first hand as opposed to those in a film or on TV are better. Try and find examples that the students can observe on campus or at home. Pull examples from current events like, for instance, explaining the cause for a design failure of a collapsed bridge recently in the news. Explain the basic principles behind a new or commonly used product like the fluid mechanics aspects of a Bernoulli disk drive in a computer.
4. Allow ample time in class to discuss the example.
5. Consider having the students prepare a written report to document what they have learned. Have them include a list of the basic principles involved.

Categories and Types of Practical Examples

Practical examples can be grouped into two broad categories: A) those that help in the Explanation of Theory and New Concepts, and B) those that illustrate the Application of Basic Principles. In addition, practical examples can also be broken down into different types based on the format in which they are used. For example, one can design practical examples that are based on: a) analogies, b) observations, c) demonstrations (experimental or mathematical), d) sensing phenomena, and e) observing secondary effects.

Explanation of Practical Example Types

1. Analogy: The analogy is a very helpful tool for explaining new concepts. Here, the instructor links the new concept to an idea which the students can easily picture in their minds (Category A). An example of an analogy would be to explain the concept of the conservation of energy in terms of money in a bank. One can imagine the money in a checking account as being analogous to kinetic energy. Similarly, money in the savings and money market accounts can be thought of as being analogous to pressure and potential energies, respectively. Just as money can be transferred between the three different accounts, so can energy between the three different forms. The concept of frictional energy losses can now be easily related to the debiting of money from the accounts (say, for paying the rent).

2. Observations: Observations that the student can make outside of class can help demonstrate basic principles being currently studied in class. The example can be

carried out as a take home assignment where the students are required to go and observe a phenomena that they can readily see, feel, hear and smell, and later summarize their observations. The students bring their observations to class and the instructor leads a discussion of what the students observed and what those observations mean. This type of exercise not only helps with the understanding of a new concept or basic principle but teaches the students how to observe a phenomena before trying to analyze it. (Categories: A & B)

3. Demonstrations: (Experimental or Mathematical) The demonstration example can be done either as an experimental exercise carried out in class with small experimental models, or as a mathematical exercise carried out on the "chalkboard" to explain a physical phenomena. This can be particularly instructive when the students are aware of the phenomena but are not able to explain the science behind it. (Categories: A & B)

a) Experimental: An experimental demonstration requires physical equipment. While finding the right equipment may not always be possible, some examples require materials as simple as a paper clip or piece of paper. For instance, the factors affecting the aerodynamic drag and lift forces on an object can be demonstrated with a simple piece of writing paper. Hold a flat sheet of paper parallel to the floor and drop it observing its rate of decent. Then take the same sheet of paper crumple it up, drop it and observe its rate of decent. In both cases you have the same material, the same mass, and the same gravitational force acting on the system. Therefore, these parameters can be eliminated from consideration. By further eliminating other parameters, the students can be lead to understand that the important parameter is the aerodynamic drag acting on the two different objects. Similarly, important governing parameters in other systems could be deduced. For instance, tests could be run with the same object shapes but with different projected areas. By observing how the time of fall depends on the various parameters, the students could arrive at the main governing parameters.

b) Mathematical: The purpose of a mathematical demonstration would be to explain, using the theory developed in class, the science behind some phenomena that the students have seen or heard of. This can be particularly enlightening if the phenomena is such that everyone knows about it, but few realize what really is happening. For instance, the term valve float in an Internal Combustion engine can be explained by modeling the valve as a train of solid links and springs, and then writing the equations of motion for the valve.

4. Sensing: Sensing examples are designed so that students can "feel" the science behind the phenomena. The goal here is to have the students carry out experiments that

allow them to sense the different parameters that enter into the theory. An excellent example of this would be to study the relationship between speed and torque for a gear system using a ten-speed bicycle. The students' assignment would be to flip their ten speed bicycle upside down, switch through all the gear combinations while pedaling it by hand, and physically sense how the speed and torque for a particular gear setting are related. Clearly, the emphasis in this technique is not to teach or explain a new concept but to give a known concept more meaning by having the students sense it. (Category B)

5. Secondary Effects: Secondary effects demonstrate the fact that sometimes the explanation of an engineering phenomenon is not obvious. The purpose here is to get the students to really consider all the possible explanations besides the most obvious one. A classic example of this would be the observation of the direction of movement of a helium balloon tied to the floor of a car when the car accelerates. Typically one would expect the balloon to move backwards when the car accelerates due to the inertia of the balloon. This would be the case if a steel ball were to be suspended from the ceiling of a car. In reality, the students will notice that the balloon moves forward as the car accelerates. An investigation of the forces acting on the balloon can be done either as a homework assignment or as a class discussion. By doing so, the students should eventually come to realize that the balloon is pushed forward by the buoyancy force acting on it. As the car accelerates, the air in the back of the car is compressed slightly, resulting in a density gradient from the front to the rear of the car. The helium in the balloon is lighter than air and therefore experiences a buoyancy force in the horizontal direction.

More Practical Examples

1. Baseball Bat Fracture Example (Strength of Materials, Material Science)
(Categories: A & B; Example Types: Observations, Demonstrations and Secondary effects)

Goal: Understand why the proper way to hold a wooden baseball bat is with the trademark or label facing up.

This example demonstrates the need for critical observation and the application of basic principles. As a first step towards finding a solution, the student needs to observe or guess what would happen if the bat is *not* held the right way. The answer to this (from either actually trying it out or by observing someone else do it) is that the bat is likely to break. The next step is to apply the basic theoretical principles and rationalize why this is so. The actual analytical process may proceed as below:

- Investigate how the bat is loaded and how it may fail. For instance, does the bat fail in tension, torsion or bending?
- Realize that the bat, in this case, is acting like a short beam in bending which implies that transverse shear can not be neglected (typical assumption made in Strength of Materials class)
- Draw a free body diagram of the loading and a stress cube for the type of loading present.
- Look at a baseball bat and sketch the cross-section of a baseball bat and describe what is seen.
- Investigate how the orientation of the bat and, therefore, the wood fibers might affect its ability to carry the loads (stresses) present.
- Look at a broken bat and draw conclusions as to what the mode of failure was and how it relates to the orientation of the bat.

Conclusions: The students learn by making observations and by applying basic theoretical principles that the bat is more resistant to shear stress with the label up. The dependence is due to the orientation and size of the fibers in the growth rings which affect the surface area of contact between fiber bundles. They learn that the bat should be modeled as a short beam with a transverse load, and that a long beam assumption is not appropriate in this situation.

2. Water Rocket example (Fluid Mechanics and Thermodynamics)

(Categories: A & B; Example Types: Demonstrations (experimental & mathematical) and Sensing)

The example consists of having the students model a toy water/air rocket (purchased at a toy store for about \$2) using the principles of conservation of energy, Newton's second law of motion, the ideal gas law, and the phenomena associated with nozzle flows.

Goal: Predict the height that a rocket would rise, given a certain amount of water and air pressure inside the rocket. When the modeling is completed the students would launch the rocket outside, and compare their observed results to the predicted results.

Conclusions: In this example the students are required to apply basic principles learned in more than one class to a real example which they can physically observe. This not only helps to clarify the basic principles but also serves to tie together different courses. This type of example also teaches the students that the theories learned in class have real world applications.

3. Merry-Go-Round Example (Dynamics or Kinematics)

(Category: A & B; Example Types: Demonstrations and Sensing)

This example could be given as an out-of-class assignment or done as an in-class assignment.

Goal: Illustrate the idea of relative motion and moving reference frames. The example consists of having two students go to a play ground and have one student throw a ball from a rotating merry-go-round to another student standing on the ground. The students would then trade places and repeat the experiment and record their observations of the flight path of the ball. To the student on the ground, the ball would appear to travel in a straight line, as it does relative to the earth. To the student rotating on the merry-go-round the ball would appear to move in a curved path away from the student.

Conclusion: This example helps the students to get a physical feel for what is being explained in class. Many engineering courses involve abstract concepts, and the students have a hard time visualizing the engineering phenomenon. However, by actually experiencing the phenomenon, students are better able to visualize and understand the concept.

II. SHOW AND TELL

Reversing Student Roles

The "Show and Tell" technique is another form of the "Practical Examples" technique. However, in this technique the role of the student is reversed to that of a teacher, thereby changing their perspective of the problem. The basic premise of the "Show and Tell" technique is that if one can explain a concept to someone else then he/she truly understands the concept.

Scope

A typical "Show and Tell" project would require a student or a group of students to explain a given theory or phenomenon to the rest of the class and also demonstrate a physical example that helps visualize the phenomenon. Almost any example that you can convincingly demonstrate in a classroom would be appropriate for a "Show and Tell" project. However, it should be remembered that as with the case of the "Practical Examples" technique, the concept to be explained by the students should be relatively simple and straight forward. The purpose of this exercise is to challenge the students to come up with a creative solution to the problem at hand without overwhelming them. In order to avoid embarrassing situations and to ensure that the demonstrations are useful to the entire class, it is also important for you to know before hand what the students plan to present.

Example: Explain and demonstrate the Magnus effect

The magnus effect is a fluid dynamics phenomena observed when a projectile in flight is spinning. The spinning projectile moves in a direction perpendicular to both it's main path and rotation axis.

Goal: The student or group would be given the assignment to both explain and demonstrate the magnus effect in class. The level of the expected explanation would depend on the level of the course and the philosophy of the teaching assistant. This particular example could be explained using potential flow theory (mathematically) or more intuitively using the ideal of streamlines and Bernoulli's principle without rigorous proof.

For the demonstration the students use whatever equipment or apparatus that they can access. In the present case, one possible idea would be to use a cardboard tube from

a paper towel or toilet roll and a piece of string. The student would wrap the roll with the string, stand on a chair holding the free end of the string and let go of the roll, causing it to unwind from the string and move down. In addition to imparting a downward velocity, the unwinding of the roll also causes the roll to spin. When the string is completely unwound, the roll will tend to move perpendicular to the spin axis (horizontal to the floor) as it falls to the floor. The horizontal direction of movement of the roll will depend on the direction of rotation of the roll. The students could demonstrate this by starting with the string wound in clockwise or anti-clockwise directions. Other variations of this demonstration would be to bring in a ping pong ball and paddle and demonstrate the magnus effect by hitting the ball with different types of spin and watching the trajectory of the balls. The same idea could be demonstrated outdoors by pitching a baseball.

Conclusions

Putting the students into the role of a teacher makes the students look deeper into the assigned problem. The students will be forced to clarify their thinking and understanding since they must explain to their peers the phenomena that they are demonstrating. In searching for examples outside of class or for demonstrations that can be performed in class, the students will be compelled to look for connections between theory and practical application.

III. CASE STUDIES

Bringing “Real-Life” Scenarios into the Classroom

An engineering case study is an account of an actual engineering activity, event, or problem containing some of the background and complexities actually encountered by a practicing engineer. Since cases are accounts of “real-life” engineering activity, they help the students to better relate theory to the “real-world”. Cases often involve concepts from other disciplines like marketing and management, concepts that a practicing engineer needs to know anyway. In addition, the case method promotes discussion in class and feedback from the students.

Scope

Engineering case studies can be included at all levels of the engineering curriculum. The hardest part of using case studies is finding cases that fit with the class material. This however should not deter you from using the case method as there are over 200 cases in Wendt Library alone, not to mention many more texts on case studies. Professors, other TAs, or contacts in industry are other great ways to find cases. With a little work, it should not be too hard to find a good case for any class.

Strategies

Students are usually given written material regarding a case and asked to read it and answer a series of questions pertaining to various aspects of the case. The students can be required to work either individually or in groups. The following are some tips to remember when using a case study:

- The case study questions may increase the amount of work the students have to do outside of class. Care must be taken to balance this extra workload against other homework assignments.
- When using case studies found in the library, do not stick to using the questions given with the case. Generate new questions that directly fit the topics covered in class.
- While the questions that are assigned form the basis of the discussion, be prepared with other questions in order to guide the discussion.
- The goal of the case should be kept in mind at all times. Keep the discussion from drifting away from this goal.

- Above all, be thoroughly prepared for the discussion. Poor preparation will lead to frustration among the students.

Example: Design Change for a Walkway

The case study that follows was used in a design course taught in the College of Engineering. The case helped students discuss how changes in a design caused during manufacturing and construction can affect the safety of the overall design. The students considered the following problem: *The on-site engineers want to know if they can change part of a design to ease construction. As head engineer, would you allow the change, and why or why not?* Pictures of the original design and changes in the design are shown in figure 1.

Figure 1: Close-up of the change of the design of walkway.

The above material described the failure of the walkway in the Hyatt Regency Hotel. The collapse occurred due to a shear failure of the beam when a large group gathered on both the upper and lower walkways to watch a band playing in the courtyard below. In the first design, the beam holds the weight of only one of the walkways. In the modified design, the section of beam between the rods carries the weight of both walkways. The failure occurred in this section of the beam. The TA did not disclose the effects of the design modification while handing out the case materials; the students were simply asked if they would allow the change and to include any calculations to support their claims.

Conclusions

About a quarter of the class decided that they would allow the change while the rest decided that they would not. However, the students who would not allow the change produced a variety of answers, not all of which were close to the right answer. These students who produced the right answers were asked to describe the failure mechanism

to the rest of the class. The TA graded the students' work more on the amount of thought put into the case rather than on getting close to the correct answer. The whole exercise took only one full class period in addition to the time required for grading.

IV. GUIDED DESIGN PROJECTS

Introducing Practical Design Experience in Classrooms

Guided designs projects aim to bring practical design experience into the classroom. Often conducted over a period of a semester, the projects give students an opportunity to work in a team environment, apply theory learned in the classroom, and learn about industrial design methodologies.

Scope

Guided design projects are appropriate for any level, but are often reserved for junior and senior levels. As with the case method, choosing a project is typically the hardest part. Using guided design projects usually requires a lot of preparation by the TA. One of the best ways to have students appreciate the industrial design methodology is to have them redesign existing systems or products.

Strategies

The following are some tips to remember when using a guided design project:

- Realize that the project is not as important as the thought processes that go into determining a design. It is not important that the students determine an optimum design. What is important, however, is that they experience the design process.
- Starting before the semester, determine the scope of the projects and the goals for the class. It is important that the scope of the project is reasonable, and care must be taken to ensure that the students are not overloaded.
- When possible, divide the design into sections. This spreads the work for the students and the grading duties over the semester. Design teams of two or three students are frequently used. This allows for in-depth projects, reduces the grading load of the TA, and promotes interaction among the students.

Example: Redesign of a parking garage gate

The following guided design project was used in a course on the mechanics of materials. The goal of the project chosen for this class was to redesign a gate at a parking garage so that it deflected on impact from a car. The gate is required to deflect

upon impact in order to avoid serious structural damage to the car. The project was divided into three parts so that the work would be spread over the semester.

The first part involved brainstorming to determine the best methods to meet the requirements. The students worked together in teams generating ideas. Then the entire class spent part of a lecture discussing the various ideas. In the debate, the TA guided the class towards a consensus about a design that would satisfy all requirements and yet be easy to complete. The student assignment for the first part was to write up and hand in a summary of their two best designs, the advantages and disadvantages of each, and which design that they would choose and why.

The second part of the project involved determining the loads on the gate. This required the students to synthesize knowledge from several courses that they had taken earlier. Also, the TA had to devote extra time in class and during office hours to explain methods for determining loads on a structure.

The final part of the project involved actual measurements and safety considerations. Having determined the loads, the students proceeded to complete the final part of the project where they determined the actual sizes of the various components used in the design. As a last step, the students used failure theories discussed in class to ensure the safety of the design.

Conclusions

The student response to this project was encouraging. They said that they enjoyed the project despite the fact that they had to work harder. The students felt that the class had a clear purpose and that the practical design aspect of the project improved their understanding of the theoretical sections covered in class.

V. OPEN-ENDED LABS

Making Students Think Deeper

Open-ended laboratory classes can be broadly defined as classes where the students are encouraged to design their own experiments or devise their own experimental strategy, rather than required to follow a rigid set of experimental guidelines specified elsewhere as in a lab manual, for example.

Scope

Laboratory classes can be made open-ended to varying degrees depending on a number of factors including the autonomy that the TA has in changing the course structure, the facilities available, and the degree of difficulty that the TA perceives to be appropriate for the class. One can think of three general areas where a laboratory class can be made more open-ended: 1) the **experiment setup** itself where the students design an experimental setup to achieve certain goals, 2) the **experimental design** where the students decide the scheme to be followed for data collection to achieve a prescribed goal, given a certain experimental setup, and 3) **data analysis and report writing**, where the students decide how the data is to be analyzed and reported. Additionally, if none of the above options are feasible, the TA can consider making the **laboratory briefing session open-ended**.

Open-ended Experiment Setup

A simple but effective example of an open-ended lab setup comes from a mechanics of materials course. A few weeks into the semester, the TA divided the class into teams of two or three students. As a part of a course project, the teams were required to experimentally test the material properties of any household object that they were interested in, write a report, and present their results to the rest of the class. The TA initially offered suggestions regarding the different experiments (like tensile testing, compression testing and bending tests) that could be run, different materials that could be tested (like golf balls, beer cans, eggs, plastic bags, scotch tape and fishing line), while also encouraging the students to exercise their creativity in finding test materials or experiments. The teams were allowed complete freedom in choosing the equipment, experimental parameters, and the data analysis methods. The TA mostly acted as a consultant, offering hints and suggestions. As expected, the project presented many

challenges forcing the students to come up with creative means to solve the problem. For example, how can the thickness of a sheet of plastic be measured?

Student Response: At the end of the semester the students felt satisfied that they actually designed an experiment and performed “hands on” work. It was also satisfying to the TA that the students were able to apply theoretical concepts to practical applications, and develop a sense of appreciation for the difficulties involved in designing and executing an experimental project.

Time Constraints: The biggest problem with this method is that it is time-intensive. For safety reasons, the TA had to be in the lab at all times when students were testing samples.

Open-Ended Experiment Design

As an example of the open-ended experiment design lab, consider the following experimental setup available for performing heat transfer experiments in a junior level chemical engineering laboratory. A large cylindrical tank equipped with a heating coil, a stirrer with adjustable speed of rotation, baffles for efficient mixing, an external heat exchanger through which fluid in the tank can be circulated, a pump to circulate fluid through the external heat exchanger, a thermocouple at the bottom of the tank to measure the temperature, a source of low-pressure steam and equipment to measure the flow rates. More equipment such as additional thermocouples and insulation are available in the lab stockroom.

In the standard lab format, the class is divided into groups and assigned specific experiments to be performed by each group. The goals of the experiments, the experimental procedure to be followed, the calculations to be performed, and the report format (including specific quantities or observations to be reported) are discussed in detail before the students perform the experiments. In an attempt to make the lab more open-ended, one of the TAs decided to run the lab as follows:

1. Students were asked to briefly study the experimental setup and arrive at an exhaustive list of experiments that could be performed. Clearly, this required the students to recollect all the heat transfer theory that they had studied and to involve themselves in collective brain-storming. The TA merely coordinated the brain-storming exercise, and offered hints and suggestions. For example, if additional thermocouples could be rigged up, the temperature distribution in the tank could be measured.

The effect of evaporative losses could be determined if the tanks could be covered with insulating material.

2. Next, the students were asked to briefly discuss the goals of each experiment and rank them according to their usefulness with respect to information content or time required to perform the experiment. For example, the students concluded that the experiment to study the effect of steam was more important than the experiment that would measure the heating effect of the pump. Therefore, they decided that they would perform the latter experiment only if time permitted.
3. Subsequently, the students were asked to organize themselves into groups and select a subset of the experiments to work on. The groups were asked to briefly sketch the details of each particular experiment such as the flow rate or stirrer speed to be used, or making sure the right parameters are changed during the experiment. The TA acted as a consultant, reviewing the experimental plans proposed by each group and offering suggestions. After a briefing about general safety procedures the groups proceeded with the experiments.
4. Finally, the students were required to turn in group reports in whatever format that they thought was appropriate. In addition, each group was required to briefly present their results to the class the following week.

Student feedback regarding the open-ended lab was encouraging. Most of the students enjoyed the freedom they had in designing the experiments, and the opportunity to exercise their creativity. Some students were initially uncomfortable about the lack of direction and specific instructions, while a few expressed a preference for the standard lab protocol.

TA Response: From the viewpoint of the TA, the open-ended lab was a big success. The lab format forced the students to think deeply about the theoretical concepts that were to be applied, to generate ideas and evaluate them, and to design and successfully execute an experimental plan.

Open-Ended Data Analysis and Report Writing

Students in most lab classes are given detailed instructions regarding data analysis, and report formats such as specific quantities to be reported, and specific figures to be plotted. This traditional approach reduces the workload of the TAs. They have to spend less time explaining data analysis procedures. Grading lab reports with a standard set of protocols is easier. However, it does not allow the students to think deeply about the material or give them an opportunity to express their creativity.

In an effort to make the lab report writing process more open-ended, a COE TA adopted the following strategy:

1. Hand out very brief information about expected report formats. Suggest possible calculations, tables, and figures to be presented.
2. Have the students work on a rough draft or outline of the report and discuss their report outline with the TA during office hours.
3. Suggest modifications and have the students turn in the final draft during lab the following week.

Student response: As can be easily guessed, the initial student response was marked by frustration and pessimism, for the simple fact that they hadn't done anything like this before. The students' attempts at designing their own reports were half-hearted, and the students required a lot of hand-holding. However, as time progressed, they grew more confident and came to believe that they were capable of producing good quality work.

TA Response: The open-ended report writing format forced the students to think about different report writing schemes and evaluate them for their effectiveness in communicating the results. At the technical level, it forced the students to think deeply about the data analysis procedures and the interpretation of the results, in contrast to merely churning out numbers using a calculator.

Caveats: It should be noted that making the lab report writing process open-ended does not imply a "hands off" policy. Indeed, a TA stands to be perceived by the students as being uncooperative, or more damagingly, as trying to shirk his or her responsibilities, if such a policy were to be adopted. It is important for the TA to provide meaningful and constructive feedback to the students, lest the students get discouraged and frustrated with the system.

Open-Ended Laboratory Briefing Sessions

Often it is not feasible for the TA to make a lab class open-ended. In this case, the goal of forcing the students to think deeply about the application of theoretical concepts and the design of the experimental plan can be achieved by making the laboratory lecture open-ended. The thought process that goes into designing an experiment can be simulated in a lecture by adopting the following strategy:

1. The TA introduces the goal of the experiment and organizes a brainstorming session by posing questions such as, "The goal of today's

experiment is to measure the viscosity of glycerol as a function of temperature. Can you suggest a few ways of doing this and explain the operating principle ?” The TA then collates the ideas generated, has the students discuss the pros and cons. At this point, the TA directs the students’ attention on the technique prescribed in the syllabus by saying, “Now that we have discussed the different possible methods, let us focus on the method that we will be using today, the capillary viscometry technique”.

2. In the next stage of the lecture, the TA generates a discussion of the details of the experimental apparatus and the experimental technique by posing questions such as: “Why is the capillary designed in such a fashion”, “How is the pressure drop problem addressed in this design”, “Why and how can we calibrate the viscometers”, “How can we maintain the viscometers at different temperatures”, “How should we process the data”, “What quantities do we plot in order to obtain the viscosity”.
3. Finally, after a brief recap of the important aspects of the experiment the students are allowed to proceed with conducting the experiment.

Student response: Most of the students agree that this technique “makes them think” and “helps them appreciate the science behind the experiments”. It also calls for a lot of class participation by the students. Occasionally, if the call for a discussion does not evoke sufficient responses, the TA may be required to call on students to answer questions or generate ideas. It should be remembered that some students dislike being called on to answer questions in class. Asking students to share ideas with a partner or in small groups first, generates more ideas and makes the students feel more confident about sharing their ideas.

Time Constraints: Organizing brain-storming sessions in lieu of the standard briefing sessions is bound to cut into the time available for conducting the experiments. However, the pay-off in terms of the improved students’ comprehension of the “science behind the experiments” makes the open-ended lecture technique well worth the investment in time.

VI. THE FLOWCHART TECHNIQUE

Organizing the Flow of Thought

The technique of flowcharting, as applied to a classroom scenario, is a tool for precisely and concisely representing the flow of information among various stages in the development of a theoretical concept or in the formulation or analysis of an engineering problem. Flowcharts are a tool to organize the flow of logic and thought in a classroom, much in the way that flowcharts help in presenting the flow of materials between various units of an industrial process.

Scope

Flowcharts are one of the most indispensable tools that practicing engineers use to organize large amounts of information. One cannot imagine even the smallest unit of a manufacturing concern being constructed or operated without the aid of flowcharts. Flowcharts can be equally useful and effective in conveying and presenting engineering information in a classroom or laboratory.

Flowcharts in Laboratory Instruction

Consider the following experiment in a junior level chemical engineering laboratory to determine the viscosity of a solution of glycerol in water using a capillary viscometer. In this method, a known volume of fluid is allowed to flow through a capillary of known dimensions, and the time taken for the fluid to flow a certain distance is related to the viscosity using a proportionality constant called the viscometer constant.

One of the main steps in this experiment is to determine the viscometer constant by running the experiment with a fluid of known viscosity such as sucrose. The sucrose solutions are prepared by dissolving crystals of sucrose in water and, therefore, have to be analyzed for the sucrose concentration. An easy method for determining the concentration of sucrose is to measure its density and convert it to a concentration using published correlations. The density in turn is measured using a device called the pycnometer. The pycnometer is a carefully constructed volumetric flask which allows the weight of a constant volume of fluid to be measured and related to the density. The volume of the pycnometer itself needs to be calibrated using a fluid of known density such as distilled water.

As mentioned earlier, the viscosity of sucrose can be interpolated from published tables once the density is known. This in turn allows the viscometer constant, and subsequently the viscosity of glycerol (the goal of the experiment) to be determined. Finally, as a check of consistency, the experimentally determined viscosity of glycerol is compared with published values. The published values of viscosity can be interpolated from tables if the concentration is known. The concentration of glycerol is determined along the same lines as that for sucrose.

As an exercise, imagine that you are a student who has just been briefed about these experiments in the standard lecture format. Now, try to recall the sequence of steps involved in the experiment. As a subsequent exercise, take a look at the flow chart in figure 2 for 5-10 minutes and try to recall the sequence of steps in the experiment. Which method is more efficient in communicating the flow of thought and logic in the experiment?!

Student response: The students strongly agreed that the flow chart technique was more effective in communicating the overall goals of the experiment. In their words, they could now “see more clearly where they were headed”. The students felt more confident doing the experiments since they had a “road map” in front of them. Additionally, the students found that the flowcharts greatly helped them subsequently while analyzing the data and writing the lab report.

Comments: It is possibly better to derive the flowchart on the chalk board during the lab briefing session and distribute previously prepared ones at the end of the class. This allows the students to “see where the TA is coming from” or understand why the flowchart looks the way it does. Better yet, the students can be required to create their own flowcharts during the briefing sessions.

Flowcharts in Lectures

Students often express concerns about not being able to understand where a lecture is headed or how the concepts taught in previous lectures relate to the concepts being presented in the current lecture. Flowcharts can be used effectively to address this concern. Flowcharts are very useful in emphasizing the flow of thought in a presentation, or in relating previously covered topics to the present material. One COE TA has made flowcharts an integral part of every lecture. The lecture starts off with the TA partitioning the chalkboard into two sections; one for presenting the lecture and the other for developing a flowchart as the lecture progresses. At the start of the lecture the flowchart consists of a single block where the goals of the lecture are clearly spelled out.

As each concept is presented and the lecture proceeds towards the goals, the flowchart is updated by adding more blocks to indicate the significant concepts and arrows connecting the blocks to indicate the flow of thought. Since the flowchart always stays in a corner of the chalkboard, the students are constantly reminded of the goals of the lecture and the concepts that have been covered in the lecture. The flowchart, which is essentially a summary of the lecture, also makes it easy for the TA to recap the lecture at the end of the class. For the same reason, flowcharts come in handy for students to review lecture material before exams.

Student Use of Flowcharts to Tackle Engineering Problems

Flowcharts can be especially helpful in solving open-ended problems. Students can prepare flowcharts alone or in groups to show processes and help solve open-ended problems. A new module to help students create flowcharts will be available for 1995-96 from the Technical Communication Division, Department of Engineering Professional Development. The module was developed with support from IBM.

Figure 2. Flowchart showing the sequence of steps in the determination of the viscosity of glycerol.

VII. OPEN-ENDED QUIZZES

Moving Students Away From Memorization

The open-ended quiz is intended to stimulate students' creativity and to help students to think deeply about the material covered in lectures. In contrast, straightforward "Given this, calculate that" or "Plug and chug" type of quizzes merely encourage students to memorize equations and formulae.

Scope

As in the case of the other open-ended teaching methods, the scope of the open-ended quiz method is only limited by the creativity of the instructor and the constraints imposed by the system.

Examples

An interesting example of the open-ended quiz method comes from Dr. Felder, professor of chemical engineering at the North Carolina State University (reference his article). For one of the mid-semester quizzes in a Graduate level course in chemical reactor design, Professor Felder¹ gave a five-week take-home exam that asked students to make up and solve a final examination for the course! The students were told that if they produced a straightforward "Given this and that, calculate that", they would receive a minimum passing grade, and that to receive more credit, they would have to demonstrate a deeper understanding of the material, the ability to apply techniques from other disciplines, and the ability to evaluate the value of a design, product, or system.

The above example, while probably one of the most open-ended exercises that can be thought of, is also time consuming. The goal of making students think deeply about the material can be achieved even in a 15 minute quiz. For example, students can be asked to solve problems that do not specify all the information that is needed to arrive at the answer. The students are then forced to think about what other information may be needed, and how they might go about obtaining the needed information. Some other variants of open-ended questions are:

¹ Felder, R. M. (1987, January). On creating creative engineers. Engineering Education, 77(4), 222-227.

1. Make up a problem which has more information than what is needed to solve the problem. The students must now think about what pieces of information are critical to solving the problem at hand.
2. Make up a problem that has the students come up with a list of different ways to accomplish a specific task. For example, come up with different ways to measure the flow rate of water in a pipe. The discussion of the feasibility of various methods will help students acquire the ability to critically evaluate different solutions.
3. Have the students assume that they are teaching the class and come up with creative ways to teach that class. In addition to helping the students think creatively, this also provides useful feedback about the direction that the students would like the TA to take.
4. Have the students come up with creative quiz questions.
5. Have students come up with different analogies to teach difficult technical concepts.
6. Assign or make up a problem that requires the students to use their engineering judgment.

VIII. BRAINSTORMING

Encouraging Creativity

The brainstorming technique is widely used in industry and academia to encourage participants to generate ideas in an unhindered manner. In an academic context, brainstorming encourages students to participate actively in idea-generation exercises and experience benefits of a multi-dimensional approach to analyzing problems or solutions.

Scope

The brainstorming technique is applicable to all levels of the engineering curriculum and to all teaching scenarios - labs, lectures or discussion sections. It is especially useful in design courses since it calls for a multiple-answer-multiple-dimension methodology rather than the usual single-answer approach to problems. The brainstorming technique can be implemented in a number of different ways as follows:

- 1. Structured:** The whole class is given a topic to discuss and each student is called upon to contribute an idea. The advantage of this method is that all students participate and the more vocal students tend not to dominate the discussions. The disadvantage is that the discussions usually do not flow freely as in an unstructured session, and can make some students feel pressured and uncomfortable.
- 2. Unstructured:** Students are allowed to contribute ideas as and when they think of them. This approach allows for a freer flow of ideas and a more relaxed environment. The drawbacks to this approach are that it can lead to the students not responding at all or to a few students dominating the discussions.
- 3. Group:** This is a structured approach except that the class is broken into small groups and each group presents its ideas after an allotted amount of time. The advantage of this method is that the students are likely to be more at ease and willing to express their ideas. This also promotes synergy and communication among the students. One obvious drawback to this method is that it more time-intensive than the other two methods.

Guidelines

The following guidelines should be followed with any of the above methods:

- Make sure that everyone agrees on the question or issue being brainstormed. Write it down on a chalkboard, for example, or give handouts.
- Never criticize students' ideas or allow students to criticize each other.
- Do not allow students to reject ideas initially. Ideas should not be weeded out until the brainstorming is completed. This keeps the solution path from becoming prematurely narrowed.
- Write every idea down. Use a flip chart, blackboard, overheads, post-it notes, or other visual methods.
- Use the words of the speaker when recording; do not interpret.

Examples of Brainstorming Applications

1. Analysis of Lab Equipment

(Example from ME 370, "Energy Systems Laboratory", Senior level ME lab course)

In the ME 370 "Energy Systems Laboratory", Senior level ME lab course, students run experiments using equipment that have complete computerized data acquisition systems. While data acquisition systems allow the students to collect a large amount of precise data, they also reduce the creativity and thought that is required of the students to run the experiments. To better involve the students in the experiments and to help them think more deeply about the experimental setup, the TA initiated an impromptu brainstorming session on the instrumentation for an Ingersol Rand double-acting reciprocating air compressor. Specifically, the TA asked the students to consider the following questions:

1. What are the important performance parameters needed to characterize the performance of the compressor?
2. What measurements are necessary to determine or measure the important performance parameters?
3. What instrumentation could be used to take the necessary measurements?

The students initially considered the first question and suggested several ideas. The TA then initiated a discussion of the generated ideas and guided the class towards a consensus about the correct set of parameters. The class then moved on to consider the second and third questions using the same brainstorming format. After discussing the final question the class proceeded to review the actual equipment instrumentation and compare it with the instrumentation scheme that they had arrived at.

The entire brainstorming exercise required only 45 minutes. It served as a review for the students, and proved to be a very interesting learning experience for both the students and the instructor. The students came away with an appreciation for the amount of detail and planning that goes into designing experiments.

2. Optimal Design of a Journal Bearing

(Example from ME 748, "Optimal Design", Taught by Professor Seireg)

The critical step in optimal design is in determining the proper objective function that is to be minimized or maximized. The objective function is an equation in the independent variables and design parameters of the problem. The objective function is minimized or maximized by varying the independent parameters within the given constraints while keeping the design parameters constant.

In the following example, Professor Seireg organized a brainstorming session on the optimal design of a journal bearing. The independent variables, the design parameters and, the constraints imposed on the design are summarized in the table below:

Independent Variables (To be optimized)	Length of the bearing - L Radius of the bearing - R Radial clearance between journal and bearing - C
Design Parameters (To be kept constant)	Load to be supported - F Speed (or speed range) bearing must operate at - N
Constraints on Design (Physical or other limitations)	Minimum oil film thickness allowable - h_{\min} Maximum oil temperature allowable - T_{\max} Bearing stability criteria

The goal of the brainstorming session was to determine the proper objective function $U = f(L, R, C; F, N)$ which can be minimized or maximized by varying the three independent variables L, R and C. A summary of the class responses are given below:

- Minimize the oil flow rate (Q) required for lubrication
- Minimize the maximum temperature rise of the bearing (ΔT)

- Minimize the overall volume of the bearing (V)
- Minimize frictional losses encountered while running the bearing. The frictional losses are equivalent to the energy generated in the oil ($= Q \cdot \Delta T$)

All of the above solutions were on the right track, but were not complete. At first glance, it appears that the minimization of the friction losses is the best strategy since the function of a bearing is to minimize frictional losses. However, Professor Seireg showed that the best objective function was one that combined two of the four factors suggested by the class. The objective function $U = Q + K \cdot \Delta T$, where K is an empirical constant, accounts for the costs associated with pumping the oil and cooling hot oil back to the original temperature.

It can be seen from the description of the problem that the task of determining the optimal design of a journal bearing is not trivial. There are a number of variables and parameters that enter the calculations, and it not very obvious what the best objective function is. However, the process of brainstorming allowed the students to discuss various solutions and understand the pros and cons of each approach.

Conclusion

Brainstorming provides a forum for students to express creative ideas. It encourages students to be open-minded when analyzing problems, an attitude that is required for solving most real-life engineering problems which have multiple solutions.

IX. QUESTION-AND-ANSWER METHOD

Encouraging Student Participation

The goal of the question-and-answer method is to draw students into active participation in teaching and learning processes. The technique also encourages students to move beyond memorization to higher levels of learning that require clarification, expansion, generalization, and inference. Often students are conditioned to simply sit in class, take notes and then study and learn the information on their own. With the question-and-answer methodology, the students can learn in real-time, as they are being taught, which helps them understand and integrate the material better.

Scope

The question-and-answer methodology is useful in any teaching environment. The approach used in applying this methodology is of course influenced by the course being taught and the teaching style of the instructor. This methodology can be used to structure an entire class, where the class consists entirely of a question-and-answer session. This approach is especially useful for discussion sections and exam reviews.

Effective and efficient use of this method requires that you have a thorough understanding of the material being discussed. It also requires that you devote time and thought into devising a set of appropriate questions for use during a presentation. It is a good strategy for you to anticipate student responses to your questions so that you can stay “a step ahead” of the students.

Goals

Thoughtful questioning attempts to achieve one or more of the following goals:

- Stimulate analytical thought
- Diagnose student difficulties
- Determine progress toward specific goals
- Motivate students
- Clarify and expand concepts
- Encourage new appreciation and attitudes

- Give specific direction to thinking
- Relate cause to effect
- Encourage student self-evaluation
- Encourage the application of concepts
- To arouse interest and curiosity
- To focus attention on an issue
- Promote thought and understanding of ideas
- Manage or remind students of a procedure

Guidelines

A well-planned list of questions is only the first step towards achieving the above goals. Merely posing questions is not enough to motivate students to move to higher levels of learning. The following guidelines may be useful in conducting successful question-and-answer sessions:

- Probe deeper after a student answers a question.
- Structure the follow-up questions ahead of time. It is a good idea to write down such questions on note cards or the margins of the lecture notes.
- Use “who”, “what”, “when”, and “where” questions to check information possessed by students. For higher thought levels, use “why” and “how” questions.
- Push students’ responses to “why” and “how” questions to higher levels of thought by asking for more explanation.
- When using questions with individuals, state the question, pause, then call on a student to answer. This leads all students to listen to the question. The pause provides time to think -- respect that period of silence.
- Summarize complicated or ambiguous answers to questions.
- Do not embarrass a student by repeatedly asking questions the student is unable to answer.
- Be reasonably lavish in the use of “good”, or other words of praise to students who give correct answers. Avoid making any negative comments after an incorrect answer -- this is sure to ensure low response on future questioning.

- Allow students the opportunity to formulate questions in response to answers from you or other students.
- Never use questions as a form of punishment. Do not call on a student just because they forgot their homework, never volunteers, disrupts the class or provides a careless response.

X. SOFTWARE

Increasing Teaching Efficiency

Software tools are widely used today in the classroom and are proving to be very effective teaching aids. One of the benefits of software tools is that they offer a means for visualization of abstract concepts and ideas. If used properly software tools can improve teaching efficiency in many instances. As a teaching tool, computer software can provide a new way to link abstract concepts with tangible visualizations. Specialized computer software offers students the option of self-learning and can also be instrumental in motivating them to learn abstract engineering concepts.

Scope

A variety of software options for classroom use are currently available. These range from software for improving communication with students to specialized software for teaching an entire course. The Computer Aided Engineering (CAE) Center in the College of Engineering and the Department of Information Technology (DoIT) at UW-Madison have access to numerous teaching-related software. Any interested TA should contact these units for further information. The CAE also maintains an on-line help system which can be accessed from CAE computers (by typing "caehelp"), from "gopher", or from "Wisc-Info". Meanwhile the TA may consider using the following three types of software in the classroom:

1. Email: Electronic mail offers a way for increased two-way communication between the TA and the students. Mailing lists for distribution of e-mail to an entire class are now available from the CAE. Effective use of e-mail requires that the students and the TA be diligent about checking their mail and responding to questions. One pitfall with e-mail is the tendency to use it as a substitute for office hours and direct contact. Although this approach may seem to be efficient on the surface, it tends to distance the TA from the students and discourages interaction.

2. Presentation: Currently available word processors like Word, WordPerfect and AMI Pro and presentation software like Powerpoint, Persuasion and Harvard Graphics offer very powerful presentation capabilities not available only a few years ago. This means that the TA can potentially present more information in a clearer manner and in lesser time. The combination of new presentation software and equipment like optical scanners (available at CAE) gives the TA the ability to select and condense material

from a wide variety of sources and present it in a convenient and professional manner. The following caveat is in order when using presentation software:

- Avoid shifting the emphasis of the presentation from the content to the appearance. It must be remembered that in engineering *function should precede form*.

3. Modeling and Analysis: Software programs for modeling and analysis of large amounts of data or complex systems are now widely available. One such program used extensively for lecture and laboratory courses in the Mechanical Engineering department is Engineering Equation Solver (EES) developed by Professor S. Klein. The advantage to EES and other mathematical analysis software such as Mathcad and Matlab is that the instructor can assign homework problems that are more in-depth in nature. These programs allow students to model systems and see the effect of varying system parameters, thereby, aiding them in developing a deeper understanding of the theory. The advanced computing capabilities of these programs also allow the TA to demonstrate complicated phenomena in the classroom. The following are some tips to keep in mind while using such software:

- Completely solve problems before assigning them for homework. Ensure that the problem is reasonable and can be completed by the students in a reasonable amount of time. It is easy to design problems that seem simple on the surface but are actually quite complicated.
- Avoid assigning problems that fit the software. The goal is to solve problems that are relevant to the course and seek software help to do so.

Example of Software Use in a Laboratory Class

The following example is from a junior level ECE laboratory course in electromechanical power conversion. The course is intended to teach the basic principles of electromechanical power conversion and power electronics through the use of student-run experiments. The students are given the lab handout detailing the procedures and goals of the experiment. After briefly reading the handout, the students are required to setup the experiment and acquire data, process the data, and analyze the results. The experiments involve the use of a number of electronic measuring instruments such as LCR meters (for measuring inductance), oscilloscopes, electric power supplies, function generators, and other related instruments. However, a majority of the students taking the course are from Mechanical Engineering who are typically unfamiliar with the detailed functions and use of these instruments. Quite naturally, the students have been unsure about proceeding with the experiments because of this reason.

Recently a user-friendly software module was developed by the TAs under the supervision of Professor R. D. Lorenz in the ME department. The module guides the students through the process of setting up the experiments and collecting the data. Using a graphical approach, the module guides the students in a step-by-step fashion through all phases of the experiment including connecting the equipment, assembling circuits, setting parameters, and collecting the data. The module also gives the students the option of learning more about the concepts behind the experiments as they proceed with collecting information. In addition, the software eliminates the drudgery of recording and manipulating the data since the data collected is now available on the computer in a ready-to-use format.

Conclusions

As a result of the new software students feel more confident, and less frustrated, about proceeding with the lab experiments. The software use makes for more efficient learning since much of the hesitation, drudgery and busy work is eliminated, leaving more time for understanding the concepts behind the experiments.

XI. Conclusion: Teaching Improvement

Monitoring Your Progress

Just as this Handbook will continue to evolve, so will your teaching style continue to evolve as you strive to match the learning styles of your students. We hope that this Handbook has sparked your creativity and provided you a basic resource from which to share teaching strategies that have worked for others. Developing a variety of teaching strategies will help you and your students build a learning community.

To develop this variety of strategies that will work for you and your students, we suggest that you monitor your progress. The following framework is one that you could use to document strategies you use and assess how they work. The framework follows the familiar "plan, do, check, act cycle" which is a continuous improvement process used in business, industry, government, and higher education.

Plan: Concept - The concept that you plan to teach

Strategy - The teaching strategy that you plan to use

Date - The day you plan to use the strategy

Materials Needed - The teaching materials that you will need

Time Needed - Plan your teaching activity so that you can accomplish all your goals

Feedback - Decide on a strategy to obtain student feedback. Consider fast feedback, written reports and observing students' reactions

Do: Execute your plan

Check: Review student evaluations

Act: Decide on what you would do next time. Stick with the strategy? Change?

We thank all those who provide material for this Handbook and look forward to getting your suggestions, examples, and references. Remember, you are a significant player in achieving "education excellence." Together, as students and teachers, we can build a learning community that will make a difference in society.

XII. FAST FEEDBACK FORM

Contributing Your Ideas!

We hope you found this handbook useful. Your suggestions will help us revise this handbook periodically. We would appreciate it if you could complete the following questionnaire.

- | | | | | | | |
|----|--|---|---|---|---|---|
| 1. | This handbook is easy to read: | 5 | 4 | 3 | 2 | 1 |
| 2. | The handbook contains useful material | 5 | 4 | 3 | 2 | 1 |
| 3. | Comments and Suggestions for improvements: | | | | | |

(fold here)

4. I'd like to have the following teaching strategy added to the handbook:

Strategy:

Course:

Concept:

Description:

(Optional) Name: _____ Department: _____

e-mail: _____

TA _____ Faculty _____ Other: _____

(fold here)

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