A Teaching Methodology that Works!
Organizing a Class

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Introduction
This is the first in a series of papers which describe a structured methodology for planning and conducting engineering classes. These papers are being developed in conjunction with a National Science Foundation-sponsored project entitled “Teaching Teachers to Teach Engineering”, establishing an annual one-week workshop for engineering educators who want to be better teachers.*

The teaching methodology described in this paper is used extensively by faculty members in the Department of Civil and Mechanical Engineering at the United States Military Academy. The methodology predates both of the authors’ experience at West Point and, indeed, may trace its origins to the earliest years of the Academy’s existence. Though it can hardly be considered new or innovative, the technique is both effective and flexible. It has been used successfully throughout the civil and mechanical engineering curricula, from sophomore-level engineering mechanics courses to senior [level] design courses. It is highly structured, yet easily adaptable to the needs of individual courses and instructors. Each year, this methodology is taught to new faculty members as part of an intensive five-week new instructor training program. Most new instructors find it so effective that they choose to continue using it for the remainder of their teaching careers. On course critiques and surveys, the vast majority of students rate it as the most effective teaching style they have experienced.

The Methodology
The process of preparing for and teaching a class generally consists of five distinct activities, performed in the following sequence:

- Research
- Organize the class
- Practice the class
- Prepare the classroom
- Teach the class

This paper will focus primarily on organizing the class. We will briefly discuss some aspects of teaching as well, but only to illustrate the implementation of a class organized according to our model. Subsequent papers will address practice, preparation of the classroom, and teaching in detail.

* This no-fee workshop will be conducted at West Point every summer, starting in 1996; it will be open to faculty from two-year and four-year institutions, from all engineering disciplines. For more information, contact the authors.
Q-describing our methodology for organizing a class, we begin by assuming that the classroom is equipped with the engineering educator's most important physical resource--a large blackboard. Indeed, we assert that the blackboard is an essential and irreplaceable tool for the effective conduct of engineering classes. In this era of high-technology multi-media teaching tools, the old-fashioned blackboard is often scorned or, at best, overlooked. Yet, having tried most of the modern electronic alternatives, we invariably return to the old standard. As a medium for presenting information, the blackboard is far superior to the projector screen or computer monitor, in the following significant respects:

- An instructor can write on a blackboard at about the same speed as a student can write in a notebook. Thus the blackboard (properly used) is an active, self-pacing means of communicating information to students.

- Information written on a blackboard remains visible and instantly accessible for the duration of the class; it can be referred to easily by students and instructor, as subsequent material is developed or discussed. Other media typically permit only a single slide or screen of information to be displayed at a time.

- The blackboard has no moving parts and requires no external source of power, except perhaps the power of imagination and creativity. And unlike most projection devices, the blackboard can be used with the lights on. In our experience, when the lights go out, the students tune out.

Modern technology clearly has its place in the engineering classroom, but we believe it should always be supplemental to the effective use of chalk on slate. Thus the blackboard is the focal point of the methodology we describe below.

Organizing the Class: A 5-Step Model

Our preferred methodology for organizing a class is as follows:

- **STEP 1:** For the given lesson, formulate a series of clear, concise, action-oriented objectives for the prescribed material. These are the essential concepts and skills we expect our students to master for this particular lesson. The number of objectives will vary with the nature of the lesson material, but 3 to 5 would be typical.

  As an example, consider an actual lesson from EM-364A, our introductory Mechanics of Materials course. Lesson MM-15, Elastic Torsion, is the first in a five lesson block of instruction which covers elastic and inelastic torsion, as well as statically indeterminate torsion members. The objectives for this lesson are as follows:

  1. Derive the elastic torsion equation.
  2. Understand the mathematical and physical meaning of the polar moment of inertia.
  3. Calculate the internal resisting torque at any point in a member subject to torsional loading.
  4. Calculate the shear stress and angle of twist in a circular shaft.
  5. Design a circular shaft using the elastic torsion equation.

- **STEP 2:** Further organize the lesson material into a logical sequence of discrete topics which, if understood by the students, will result in their successful achievement of the lesson objectives. Our intent here is to sub-divide a large, complex body of information into smaller, “bite-sized” pieces, which can be more
readily understood by students. These topics are more detailed and more numerous than the lesson objectives. They typically number between eight and ten per lesson.

The nine topics identified for our elastic torsion lesson are:

(a) WHAT IS TORSION?
(b) TORSIONAL DEFORMATIONS
(c) SHEAR STRESS DUE TO TORSION
(d) THE ELASTIC TORSION EQUATION
(e) ASSUMPTIONS USED IN THE ELASTIC TORSION EQUATION
(f) THE POLAR MOMENT OF INERTIA
(g) CALCULATING THE ANGLE OF TWIST
(h) TORSION ANALYSIS EXAMPLE PROBLEM
(i) TORSION DESIGN EXAMPLE PROBLEM

Note the correspondence between these topics and the objectives identified in Step 1. For example, Topics (b), (c), (d), and (e) support Objective 1. Topic (f) supports Objective 2. Topics (h) and (i) are particularly significant: we attempt to include an example problem in every lesson which has problem solving as an objective.

STEP 3: Develop a plan for presenting each of these topics on a 4-foot wide segment of the classroom blackboard*. The presentation of a given topic may include text, graphics, equations, or a combination thereof. The presentation is always meticulously planned, for maximum clarity and precision and for an optimum balance of simplicity and thoroughness. The completed lesson plan is recorded on specially formatted “board notes”, consisting of miniature hand-drawn pictures of the individual blackboard segments which comprise the planned classroom presentation.

The board notes for Lesson MM-15, Elastic Torsion, are shown in Figures 1(a) and 1(b). Each of the eleven numbered boxes represents the planned presentation for a single 4-foot blackboard segment. Note the close correspondence between the board notes and the lesson topics identified in Step 2. Wherever possible, each topic is fully developed in a single board segment. In Lesson MM-15, the only exception to this rule is the analysis example problem, which is spread over three segments (numbered 8-10).

One important aspect of our methodology which is not apparent in Figure 1 is the use of color. Our blackboard presentations are always executed in five colors of chalk, according to a consistent scheme developed by the individual instructor. The use of colored chalk is not merely “window dressing;” it has important pedagogical value. When used to write text and equations, colors clearly illustrate the hierarchy of ideas presented and add visual interest to the material; for graphics, the use of color greatly enhances clarity, especially for complex drawings. For example, the diagram used to illustrate torsional deformations on Board #2, Figure 1(a), might be difficult to decipher if presented in a single color; but when white chalk is used to draw the cylinder, green to depict the deformations, blue to show the torque vectors, red for the stresses, and yellow for the text and dimensions, the diagram becomes much more clear.

*At USMA, the classroom blackboards have visible seams at regular 4-foot intervals; thus the partitioning of boards is done by default. Where the blackboards are not delineated in this manner, the same effect can be achieved by drawing vertical chalk lines at 4-foot intervals.
STEP 4: Plan transitions between blackboard segments. Having subdivided the lesson into "bite-sized" pieces, we must now combine the pieces into a coherent whole, through the use of well-planned transitions.

STEP 5: Plan the use of visual aids and supplemental written material.

- We strongly believe that physical models are the best visual aids in the engineering classroom. Indeed, we attempt to do some sort of physical demonstration at least once in every class. In our elastic torsion lesson, we use cylindrical shafts made of rubber and foam to demonstrate torsional deformations; we also show steel and brass laboratory specimens which have been tested to failure in torsion.

- We often use supplemental written material, distributed to students prior to the start of class. Typically, these handouts provide the problem statements (but not the solutions) for example problems which will be worked in class.

- We avoid using viewgraphs, except when a particular form of information (e.g., tabular data from a design code) cannot be reasonably displayed by other means.

In the Classroom

Given this highly structured methodology for organizing a class, one might expect that our classroom presentations are excessively rigid or that they preclude active student participation in the learning process; but nothing could be further from the truth.

In the classroom, our instructors never lecture and never merely copy their notes onto the blackboard. Rather the classroom environment is entirely interactive. The instructor develops each topic through spirited questioning and discussion with students, constructing each pre-planned board only as the pace of the discussion dictates. Indeed the pre-planned boards become the principal mechanism for pacing the class, ensuring that material is never presented faster than the students can assimilate it and record it in their notebooks.

This structured methodology may seem constraining; but in practice it merely provides a framework, within which individual instructors have considerable flexibility to use innovative techniques and new technologies, and to express their own personalities.

How Does It Work?

At the end of every academic year, we administer a comprehensive survey to our graduating seniors. We allow them to respond anonymously and ask them to be as honest as possible in their assessment of our courses and programs. One of the survey questions reads, "Which teaching styles stand out as particularly effective?" In response to this question, over 80% of our seniors cite some aspect of the methodology described above as an effective teaching style. A few representative examples from the Class of 1995 survey:

"The instructor starts on Board 1 and goes around the room writing with you. This keeps the instructor from getting too far ahead or meandering through the material."

"The CE Department has the best method of instruction--organized board notes, super example problems, and motivated teachers."

"The way you use board notes is so methodical, I can't help but take good notes."

"★★★★★colored chalk. ★★★example problems. ★★★teaching aids (models, etc.)"
“Good board notes and example problems seem to be the best learning tools.”

“Organized board notes put the CE Department far above any other department.”

“I like the Civil Department’s style. Teach it, then work problems, then ask questions, then test. The notes on the boards were dramatically more organized than any other course at the Academy.”

“I cannot recall a single instance in which my instructors have been even remotely unprepared. The structure of class (i.e., board notes) is extremely helpful.”

“Organized notes on the board. The use of physical models to help visualize.”

“The style used by C&ME (explanation and discussion while writing notes on the board).”

“The Civil Department style--organized and focused.”

“The use of chalkboards with colored chalk!”

Does the methodology work? Given the near-unanimous affirmation by our students, we believe the answer is an unequivocal “yes.”

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Figure 1(a). Board Notes for Lesson MM-15, Elastic Torsion

3. **Shear Stress Due to Torsion**

   - \( \gamma \) is proportional to distance (\( \rho \)) from center of cross-section:
     \[
     \gamma = \left( \frac{\rho}{c} \right) \gamma_{\text{max}}
     \]
   - Assume linear-elastic behavior
     \[
     \tau = \left( \frac{\rho}{c} \right) \tau_{\text{max}}
     \]

4. **Equilibrium**

   \[
   T = \int_A \rho (\tau \, da) = \int_A \rho (\frac{\rho}{c}) \tau_{\text{max}} \, da
   \]
   \[
   T = \frac{\tau_{\text{max}}}{c} \int_A \rho^2 \, da = \text{Polar Moment of Inertia} \]

5. **Assumptions**

   - Circular cross-section
   - Homogeneous
   - Isotropic
   - Small deformations
   - Linear-elastic behavior

6. **Elastic Torsion Equation**

   \[
   \tau_{\text{max}} = \frac{Tc}{J} \quad \text{or} \quad T = \frac{J \tau}{c}
   \]

   - \( T \) = internal resisting torque
   - \( \rho \) = radial dist. from center to point of interest
   - \( c = \rho_{\text{max}} = \text{radius} \)
   - \( J = \int_A \rho^2 \, da = \text{Polar Moment of Inertia} \)

7. **Polar Moment of Inertia**

   - Geometric property
   - Resistance to twisting
   - Solid circular sections:
     \[
     J = \frac{\pi}{2} c^4
     \]
   - Hollow circular sections:
     \[
     J = \frac{\pi}{2} (c_0^4 - c_i^4)
     \]

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7. Angle of Twist:
\[ \phi_p = \frac{M}{JG} \Rightarrow \phi = \frac{M}{JG} \]

Assumptions: Circular section, small deformations

\[ \phi = \frac{LT}{JG} \]

Assumptions: C.H.I.S.L.

8. Example Problem

Given:
- Dia. = 4"
- \( G = 11000 \text{ Ks} \)
- \( t_y = 55 \text{ Ks} \)

Required:
1. Determine max shear stress.
2. Determine the smallest possible dia. (use factor of safety = 2.0)

9. Torsion Analysis:

\[ \Sigma M_x = T_{bd} - 11 + 10 - 4 = 0 \Rightarrow T_{bd} = 5 \text{ ft-k} \]

Section CD

\[ T_{cd} = 5 \text{ ft-k} \]

Section BC

\[ T_{bc} = 11 - 5 = 6 \text{ ft-k} \]

10. Section AB

\[ T_{ab} = 10 - 11 + 5 = 4 \text{ ft-k} \]

Shear stress

\[ T_{max} \text{ occurs in BC } (C \neq J \text{ constant}) \]

\[ \tau_{max} = \frac{T_c}{J} = \frac{(6 \text{ ft-k})(2/3 \times 2)}{\pi/2 (2^4)} \]

\[ = 5.73 \text{ Ks} \]

\[ \text{Ans.} \]

11. Torision Design:

\[ \tau_{actual} \leq \tau_{allowable} \]

\[ \frac{T_{max}}{J} \leq \frac{t_y}{F_S} \]

\[ (6 \times \text{ ft-k})(2/3 \times 2) \leq \frac{53 \text{ Ks}}{2.0} \]

\[ C \geq 1.20" \]

\[ \therefore \text{ Min. Diameter} = 2.40" \]

\[ \text{Ans.} \]

Figure 1(b). Board Notes for Lesson MM-15, Elastic Torsion