Innovative Teaching Methods in the Civil Engineering Curriculum at The Pennsylvania State University

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Abstract

This paper describes several innovative teaching methods that the author has implemented in four courses in order to increase student involvement in the lessons. These methods include questioning techniques, physical demonstrations, team-oriented in-class exercises using toolkits developed by the author, and lesson presentation techniques. The methods have been significantly inspired by the T^4E teaching model, which was developed at the USMA and at whose NSF-sponsored short course the author attended.

Student data both before and after the implementation are included along with faculty assessments. Comments from other assistant professors who have implemented various aspects of the model are also included as are the author's anecdotes. In the three semesters of implementation, the author has observed improved student performance as measured by written exams in addition to positive student and peer evaluations.

1. Introduction

One challenge faced by the author since entering the engineering education profession has been learning how to use the lesson time as a catalyst for student learning rather than simply a time of transmitting information. To help address this challenge, the author attended the one-week NSF-sponsored short course Teaching Teachers to Teach Engineering (T^4E) held at the United States Military Academy[1,2]. The first year (Summer, 1996), the author was a participant; the second year (Summer, 1997), he was a consultant.

This paper describes several innovative teaching methods that include the T^4E methods and those inspired by T^4E. The general goal was to increase student involvement in the lesson with the underlying premise that along with increased involvement comes increased student learning. The specific objectives of the methods were to:

a) enhance understanding and comprehension,
b) appeal to different learning styles, and
c) create an engaging classroom environment.

The implementation of these methods at Penn State required the development of an extensive number of training aids, re-organization of course material, and extensive lesson preparation. Basic descriptions of the methods and training aids are provided here along with references for more details. Student response to the author's instructional approach is provided both before and after the implementation. The available data includes both university and instructor administered evaluation surveys. Comments from peer reviews are included in addition to those from other

Penn State professors who have implemented various aspects of the T^4E model. The paper closes with interpretation of the data and student comments as well as author anecdotes.

2. Teaching Methods

The T^4E teaching model has been a significant source of inspiration for the author and hence will be briefly described. Detailed description of the motivation behind the model and its various aspects have been published in both hard-copy[1,2] and electronically[3,4] (world wide web). The T^4E model is first and foremost about effective communication. It is a well-defined plan by which to engage students directly in the lesson presentation. This plan is organized via a well-defined structure and executed via well-defined presentation skills and techniques. These include specific questioning techniques, physical demonstrations, and planned exercises. This paper focuses first on descriptions of individual techniques and then on a method for planning the use of and effectively executing those techniques within a typical lesson.

2.1 Questioning Techniques

An obvious method by which to directly engage (or involve) students in the lesson is by asking questions. One challenge for the inexperienced (and sometimes experienced) teacher is how to select and ask "good" questions. That is, how does one select and ask short, clear, unambiguous, and non-trivial questions that are also not too difficult?

One helpful approach for selecting a "good" question is to first think about the techniue used to deliver the question. The following model characterizes eight techniques; these are evenly divided into two categories: **Basic** and **Intermediate**. The category refers to the skill required in using the technique more so than the difficulty of the question itself.

Basic Questioning Techniques

1. The Basic
   `Ask the Question; Pause; Call on an individual.`
2. The Jump Ball
   `Ask the Question; Pause; "Anybody?"`
3. The Choir
   `Ask the Question; Pause; "Everybody?"`
4. The Volunteer
   `Ask the Question; Pause; (wait for a raised hand.)`

Intermediate Questioning Techniques

1. Misdirected Question
2. Blind Question
3. The Expert
4. The Expert -- Not

The four Basic Questioning Techniques are relatively self-explanatory. The description following the technique's title details the manner in which the technique should be executed. The *Basic*

question requires that individuals be known either by name or some other distinguishing characteristic. It is a good fall-back technique to use if no student initially responds to a *Jump Ball* question. The *Choir* is a useful technique for eliciting a quick response from the entire class, particularly for a question that activates or reinforces prior knowledge. The technique conveys that the answer should be readily known by all and that the question is not a trick question.

The *Volunteer* question runs the risk of being accompanied by many seconds of silence (the "null" response) while the instructor patiently waits for a response (and students avert their eyes!). It is also, however, a wonderful opportunity for the instructor to probe the students' understanding of the lesson material. For if there is no response, the instructor knows that something may be wrong. Perhaps the question was too difficult or incomprehensible. One follow-up technique for the "null" response is to ask the students to show by a raised hand if they understood the question. Or, ask who did not understand. With this latter approach, it is imperative that the instructor then select an individual who didn't raise their hand (thus implying that they understood the question). Frequently, the student really did not understand the question and did not want to acknowledge it. If this is the case, then either the question can be re-stated or the answer can be explained. It is particularly important, however, that whomever was finally "selected" to answer the question be given an opportunity to acknowledge their new understanding of the question or that they be given a follow-up question to which they can successfully respond.

The Intermediate questions are designed to keep the students "on their toes." The *Misdirected Question* refers to looking at one student while actually asking a different student the question. The *Blind Question* is one in which an individual (or everybody) is asked a question while the instructor's "back" is to the class, erasing the chalkboard, for instance. The *Expert* question refers to a student who has previously demonstrated expertise. For example, once a student has successfully answered a question, he or she becomes the "expert" for that lesson or even for that semester. The *Expert -- Not* technique reverses this scenario and is used to intergject humor but must be used carefully so as to not offend the student. An opportunity to use this technique is often found when a student provides an erroneous answer to a trivial question ... particularly if that student has correctly answered that question in a previous lesson. Another opportunity is when someone asks a question that has just been asked and answered during that lesson.

These questioning techniques should be used in a pre-planned fashion and with some variety. They require, however, that the instructor take the risk of stopping his/her "lecture" and actually *communicate with the students*. To be a successful questioner, one eventually needs to learn the students' names. For class sizes beyond 30 students, learning a student's name may initially appear to be insurmountable. Two useful techniques are to first identify students by their clothing (and begin to learn names) and to use a seating chart. The author was initially reluctant to use a seating chart for fear of negative student response. However, when using it during the Fall 1997 semester for two different classes, not one complaint was heard from 93 students.

The strategy of how one weaves these questions into a lesson plan will be discussed later.

2.2 Physical Demonstrations

The nature of most engineering disciplines lends itself to using physical models to demonstrate lesson topics. This author firmly believes that physical models are an essential part of a balanced engineering curriculum. The expense both in terms of finances and time in devloping the models can be daunting, however. Indeed, the "cost"of the traditional laboratory is one reason the author has heard for justifying the development of computer simulation/animation programs. A personal concern for the author develops, though, as to whether students retain or even develop an understanding of the real physical behavior of such "computerized" models. This author asserts that computer models are best used as a supplement rather than as a replacement for physical models.

Alternatives to the traditional laboratory include seminars where hands-on demonstrations are the focal point of active exercises and in-class demonstrations[5]. The structural engineering curriculum is ideally suited for such an approach. Indeed, the building in which the classroom is located becomes itself a model that can be discussed during the lesson. Student feedback that will be discussed later indicates that students particularly enjoy problems that relate to on-campus facilities --- facilities that the students can "get their hands on."

After being inspired by the extensive collection at the USMA during the 1996 T^4E workshop, the author developed an extensive number of physical models, demonstration models, and training aids; the number exceeds 30 at the time of this writing. The most interesting models are discussed in Meyer, *et. al.*[6] and Schmucker;[7] still more may be viewed on the web[4]. Three principle objectives in developing both the USMA and Penn State models were:

a) each model must clearly demonstrate a specific structural concept or behavior,

b) the models must be simple and relatively inexpensive to construct, and

c) the models must be durable enough to withstand rough handling.

One model that the author has developed is the Structural Engineering Toolkit[4,7] (SET) shown in Figure 1. The SET was specifically created to facilitate creation of "spur-of-the-moment" modeling ideas. The SET is composed of rods and connectors obtained from the commercially available children's toy K'Nex. The color-coded rods and connectors are easily and quickly assembled to produce a wide variety of models that represent structural elements and/or entire structural systems. The resulting models are quite durable and with imagination can also be used to create models that demonstrate specific modes of structural behavior.

The SET also facilitates both in-class and out-of-class exercises that supplement classical and numerical techniques. Each SET was sized to accommodate exercises for teams of two to four students. The in-class exercises tend to be focused on understanding relatively simple structural concepts and/or behavior whereas the out-of-class exercises permit more detailed exploration.

Figure 1: Structural Engineering Toolkit (SET)

The SET is also ideal for design projects where the students must conceptualize and visualize the project, propose alternative solutions, and even post-analyze the performance of their constructed design.

2.3 Lesson Preparation and Presentation Techniques

The technique that pulls the above techniques together and enables them to be effective is a lesson preparation device known as Board Notes[8]. This device is a clever organizational tool and was rated as one of the most valuable items of the T^4E workshop by the participants[2].

Board Notes are a specially formatted set of lesson notes consisting of boxes that represent a segment of the chalkboard. An example sheet of Board Notes for Lesson 8 of the introductory structural analysis course CE240 is shown in Fig. 2. Within the boxes, the instructor records the information in the precise manner that it will placed on the chalkboard (or overhead, power point slide, etc.) during the lesson presentation. Some versions of the Board Notes have space available for the instructor to place reminders, instructions to self, etc.

Attractive features of the Board Notes are:

- One is able see the entire presentation hence making it easier for the instructor to see the relationships between various lesson topics during the lesson in the way that the student will be seeing it;
- The Board Notes are a map of the lesson. Should the instructor become lost or confused during the presentation, it is easy to recover by glancing at the “picture” on the Board Notes;
- Creating the Board Notes is in itself a rehearsal of the lesson presentation;
- The Board Notes free the instructor from being concerned with what information will be put on the board and where it will go. Hence, the instructor can focus on the students and how they are receiving the information;
- The Board Notes are self-pacing. For this author, eight to ten boards constitute a 50-minute lesson.

- The Board Notes provide a fairly accurate image of what ends up in students' notes.

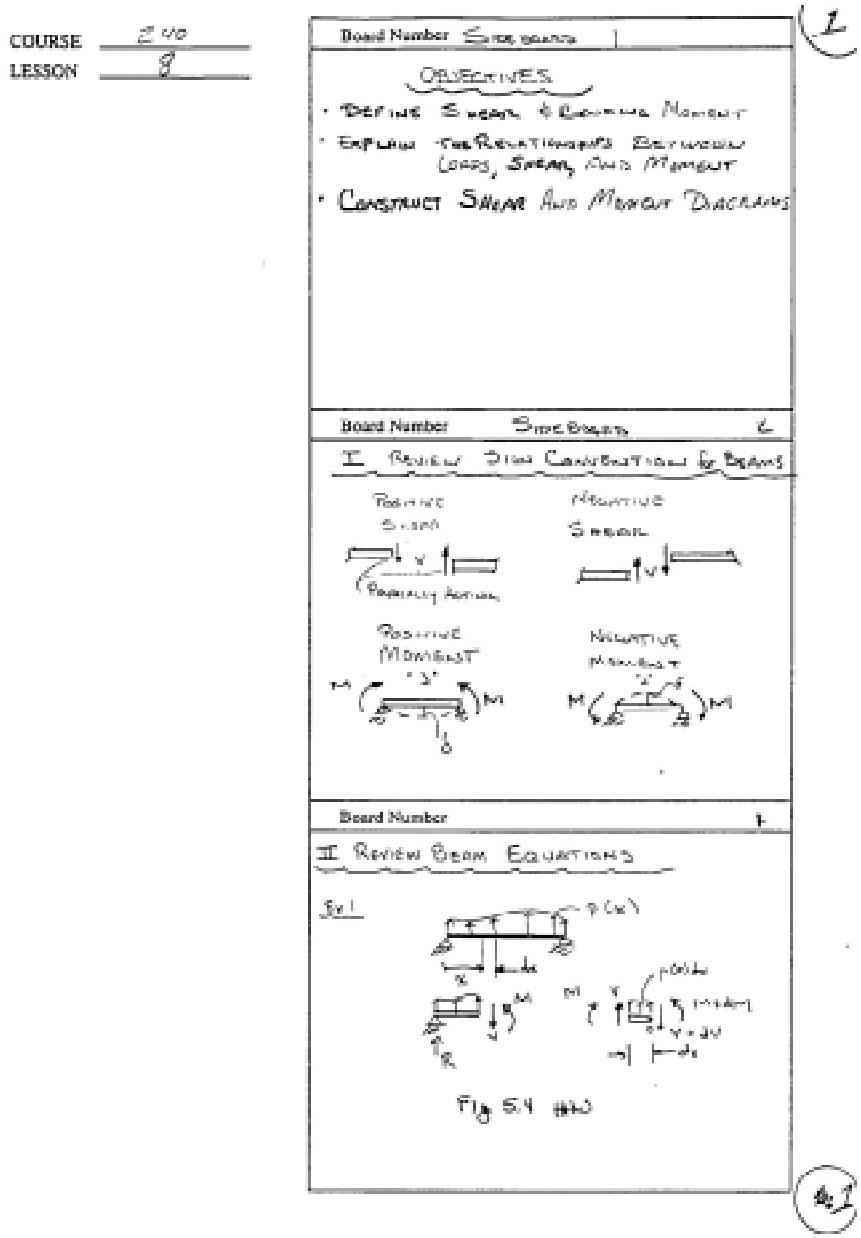

Figure 2: Board Notes for Lesson 8 of CE240

An important aspect not conveyed in Figure 2 is the use of color. Color chalk is an important aspect of the lesson presentation, not merely for aesthetic reasons but also for pedagogical value. The different colors represent the hierarchy of ideas. In the author's classes, blue is always used for major points and green is used for sub-points. Interim equations are done in white whereas more important equations are in yellow. For graphics, the colors are invaluable in providing clarity. For example, an undeflected structure is drawn in white, forces are always drawn in red,

and deflected shapes in yellow. An additional benefit is that the colors also add a distinctive feel to the class.

3. Assessment

3.1 Student Response

Three types of student data and comments were collected: formal university-administered evaluations, formal instructor-administered evaluations, and formal and informal student comments. For the purpose of this paper, the distinction between university- and instructor-administered evaluations is defined by the amount of participation that the instructor has with the administration of the evaluation. For the university-administered evaluations, the students hand-out, collect,and submit the forms for processing. For the instructor-administered evaluations, the author hands-out and collects the forms and submits them for processing.

At the end of each semester, the university administers the Student Rating of Teaching Effectiveness (SRTE) evaluation. This data has been collected each semester since the author entered engineering education (Fall 1995). The SRTE data represents the most consistent data that the author has with which to track the “before” and “after” T^4E implementation effects. The SRTE results and formal student comments are not provided to the instructors in the Civil and Environmental Engineering Department until the middle of the next semester.

The College of Engineering Instructional Services at Penn State has developed an evaluation form similar to the SRTE called the Engineering Feedback on Teaching Evaluation (EFTE). This is an instructor-administered (but university processed) evaluation and has been in broad use since the Fall 1997 semester. The results of the EFTE are immediately available and hence can be used to make mid-semester adjustments rather than waiting for future courses.

The author collected EFTE data immediately after each of two interim exams (the morning after the evening exam) and at the end of the semester; hence there are 3 EFTE data sets. The semester-end data was in addition to the SRTE data. Informal student comments have been collected by the author during each semester since Fall 1995, but the questions were not uniform nor were the timing of evaluations uniform.

The SRTE evaluations request that the student respond using a rating or ranking scale (1 = lowest rating, 4 = average rating, 7 = highest rating). The EFTE evaluations provide statements to which the student responds to the degree of (dis-)agreement (1 = strong disagreement, 3 = undecided, and 7 = strong agreement). Note that the average, or neutral value on the SRTE scale is higher than that of the EFTE (4 versus 3, respectively). This may be significant when comparing between the two sets of results. In the author's opinion, the EFTE is a more useful data set because the student responds to more specific statements than the SRTE as will be shown.

SRTE and EFTE questions selected for presentation are detailed in Tables 1 and 2 of the Appendix, respectively. Questions selected for discussion were based upon commonality

between the SRTE and EFTE and relevance to the methods discussed in this paper. Additional EFTE questions will be discussed because of their particular relevancy to this paper.

Response to selected SRTE questions is shown in Figure 3. The questions selected here are similar to several EFTE questions. The responses to those EFTE questions (only Fall 1997 data available) correlate significantly with the SRTE data in Figure 3 and hence are not shown. For reference, the topics of the questions for data shown in Figure 3 are listed below with both the SRTE and EFTE question numbers, respectively.

- Overall quality of the course (A3 and 12)
- Overall quality of the instructor (A4 and 20)
- Clarity of explanations (B1 and 16)
- Instructor preparation (B5 and 19)
- Exam effectiveness/fairness (B7 and 8)
- Intellectual Stimulation (B10 and 17)

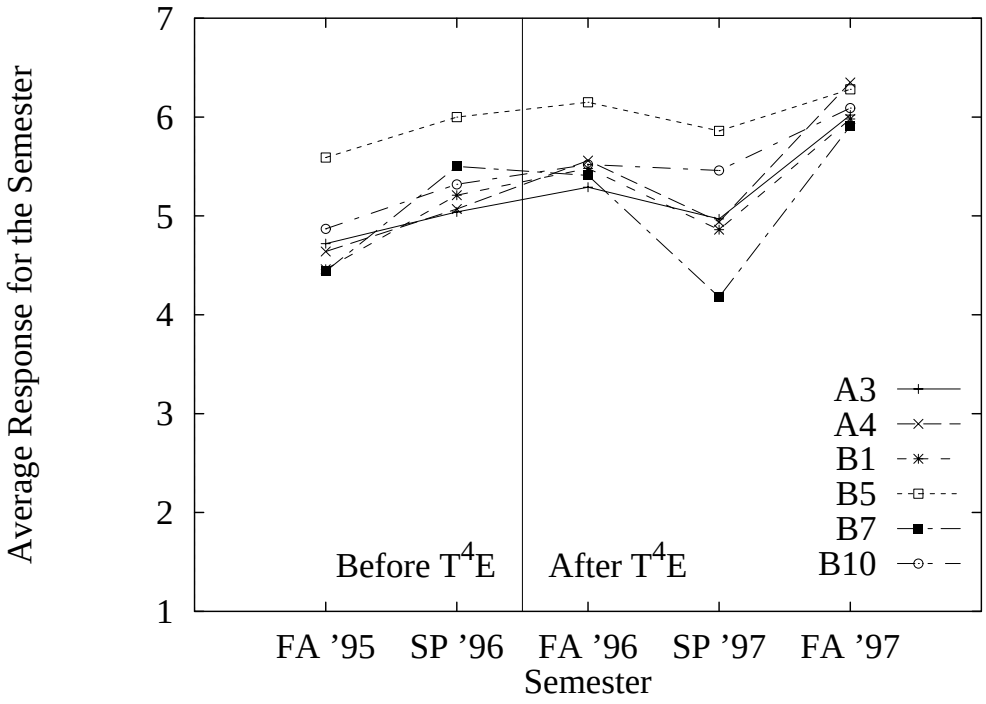

Figure 3: Selected SRTE Data Before and After T^4E Implementation (Selection is based upon similar questions from EFTE)

The data for these six questions shows a generally increasing trend with the exception of the Spring 1997 semester. Note in particular the exceptionally high rating for instructor preparation (B5 and 19). These averages are all above 6.0. Also important is that the Fall 1997 SRTE data are all above 5.5. Note that Fall 1997 data includes only data for the CE240 course. The author also taught CE447, a senior-level elective course in structural analysis. The Fall 1997 semester was the first time that author taught this course. Nearly all averages were approximately one full

point lower than the CE240 scores. Written student comments indicate that the primary basis for the lower rating was the difficult and time-consuming course project. Although many of the students enjoyed the project and felt that it was a valuable experience, most appeared to feel that it needed to be significantly restructured to fit better within the course objectives and that more weight should be given the project in the course grade to reflect the significant amount of effort.

It is the opinion of the author that the first two (of three) interim exams during the Spring 1997 had a contributing factor to the decline in student rating during this semester as observed in Fig.3. This is not to say that the author believes that students only give good ratings to instructors who give easy exams. Rather, the author had particular difficulty in creating exams for this particular class that were within the reach of the class and also satisfied the author's opinion of appropriate technical competency. In students' words, the exams were "too difficult." Yet, overall the ratings are generally positive.

Figure 4 shows that there is a similar trend towards improved evaluations for the remaining SRTE data. Again, there is a dip observed during the Spring 1997 class. It was definitely observed that the morale of the Spring 1997 class suffered during the early portion of the semester and sadly this appears to be reflected in question B2 (positive atmosphere for learning) where the average drops from 5.9 to 5.4 from the Fall 1996 to Spring 1997 semester. For the Fall 1997 CE240 course, we observe an increase to 6.2 for this question, this despite a second exam that was quite difficult for a majority of the class.

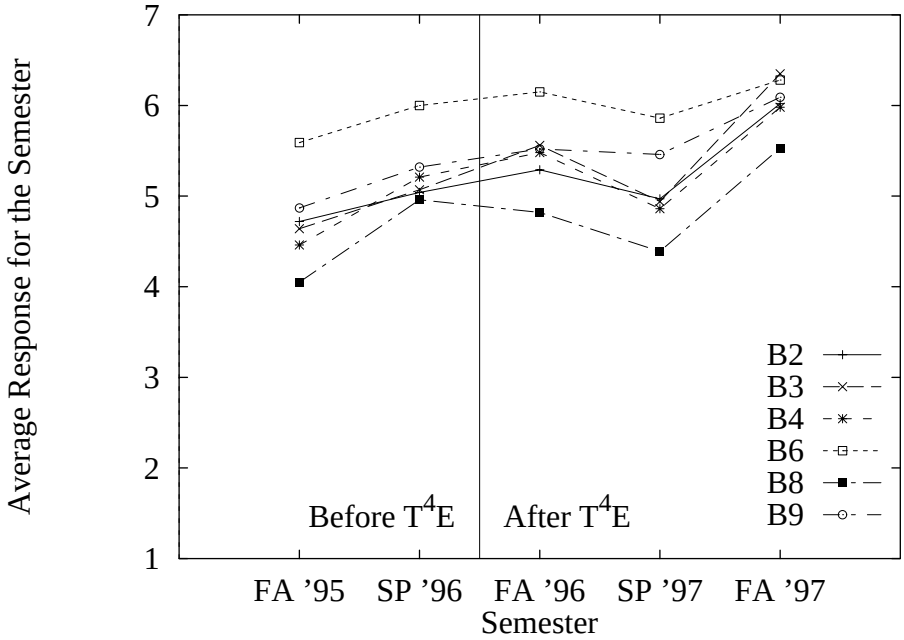

Figure 4: SRTE Data for Remaining Questions

Somewhat curiously, there is a relatively downward trend in Fig. 4 for question B8 (flexibility of teaching methods to accommodate individual differences) after the implementation of the T^4E. This is initially disappointing given that a part of the goal of this implementation is to appeal to different learning styles. The averages are still relatively positive (4.4 for Spring 1997 and 4 means an "average" rating). It would be helpful if follow-up questionnaires were used to pin-point the causality of the students' responses; this points out one of the failings of end-of-the-semester evaluations. The response from Fall 1997 suggests that this trend as reversed, but it does bear watching.

Clearly, there is insufficient data to make definitive conclusions about the role of T^4E in these trends. However, the generally positive trend and the student comments to be discussed later suggest that the student's perceive that the author's teaching is improving.

The EFTE data for selected questions during the Fall 1997 semester are shown in Fig. 5. This data represents one course, a junior-level structural analysis course. The first two sets of data were collected 12 hours after each respective exam. Hence, these should be considered to be somewhat of a "lower bound." The last set of data was collected during the last week of the semester. The student response overall is once again, quite favorable. An understandable dip occurs after the second exam as a reflection of exam difficulty. Once again, the students felt that time was a factor although the performance as measured by the exam scores was satisfactory.

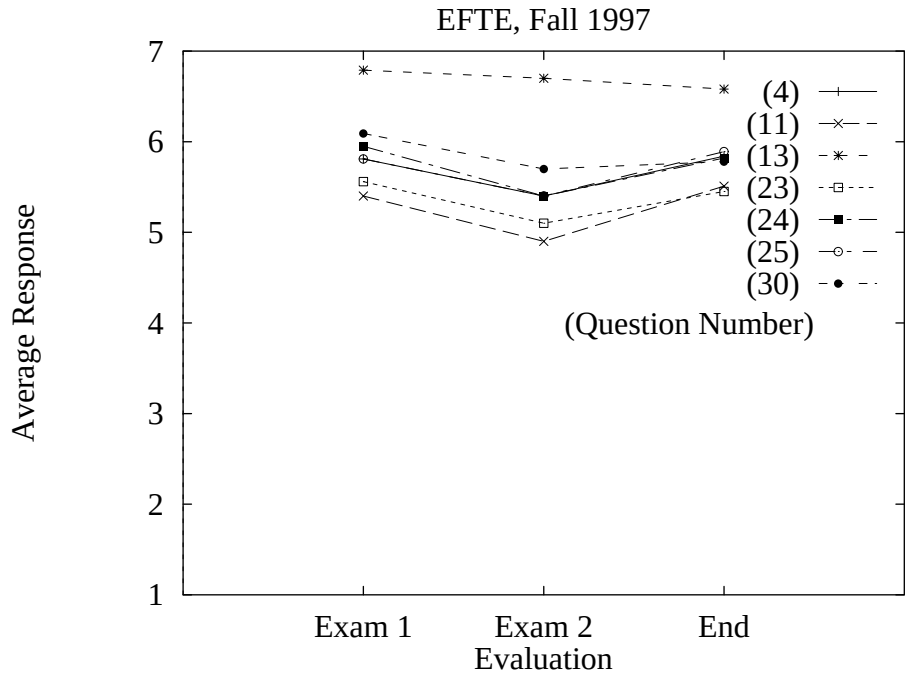

Figure 5: Remaining EFTE Data

Of particular note in this figure are the responses to questions 4, 23, 24, and 25. Question 4 specifically addresses whether "the method of presenting information in class enhances my learning." The end of the semester average was 5.84. Recall that this area was a potential concern given the Spring 1997 SRTE data. The end of the semester averages for questions 23,

24, and 25 were 5.45, 5.82, and 5.89, respectively. These questions each address specific presentation techniques. "The instructor should continue to ask questions in the manner he does; use the presentation style that he does; implement boardwork the way he does," respectively. The data with respect to physical models was not included here because the wording of the statement varied each time. At the end of the semester, given an alternative of spending money of physical models or computer software, the students chose the physical models (4.86/7). Recall that a 3 is neutral for the EFTE.

Student comments have correlated well with both the SRTE and EFTE data. Typical comments over the past five semesters have been:

> "*Keep up the enthusiasm. It makes learning easier.*"
>
> "*The design projects were interesting, especially the Kunkle Lounge project because you could see the structure you were evaluating.*" (Kunkle Lounge is a facility adjacent to the classroom building.)
>
> "*The demonstrations helped alot to clarify key points.*"
>
> "*I find myself at attention almost all of the time in this class due to the instructor.*"
>
> "*Some of the lectures were interesting especially when visual aids were used.*"
>
> "*The board presentation, the use of colored chalk to emphasize different forces and deflections.*" (Response to "What did you like best?")
>
> "*Dr. Schmucker always had a positive attitude and was always willing to listen to students, used student interaction.*"
>
> "*It wasn't boring like most of my classes. The presentations were interesting ("wacky fun noodle") and helpful.*"
>
> "*The clear organization of lectures.*" (Response to "What did you like best?")

By far and away, the item least liked about the author's courses over those five semesters have been the exams. Students clearly feel that they are: too long, too difficult, and/or not over appropriate material. The evaluation data clearly supports these comments but also illustrates that, although exam difficulty may have a partial effect on the average response, the overall evaluation of the instructor has not been seriously marked down. The one particular exception may be the Spring 1997 semester.

Overall, it is the opinion of the author that although there is room for improvement that the students are reacting favorably to the implementation of these teaching techniques. This is further supported by numerous verbal comments by the students outside of class and after the course is completed.

3.2 Peer Comments

A total of six peer reviews have been performed: three during the first semester of the author's teaching career and three during the fifth semester. The T^4E implementation began during the third semester. For no particularly reason, each peer review occurred during the same course: CE240 Fundamentals of Structural Analysis. The first-semester evaluations were all positive and commented that author appeared to have good interaction with the students and was well organized. Note from the SRTE data, however, that some of the lowest student marks are from this same semester. The fifth-semester evaluations were also positive. Two of these evaluations were a standard part of the promotion and tenure process. The third evaluation was performed at the request of the author.

Comments are listed below with the semester in which they were collected shown in parentheses.

> "*This is Mr. Schmucker's first class of his first semester. My sense is that he enjoys teaching and interacting with students, and he appears to have good teaching instincts.*" (Fall 1995)

> "*He showed confidence and the lecture was effective. I think he has a good start for his teaching career. Continue to enhance the friendly relationship with students in the classroom.*" (Fall 1995)

> "*Dr. Schmucker has obviously put a great deal of effort into the preparation and presentation of this introductory course. The students appear to appreciate this effort.*" (Fall 1997)

> "*The preparation for this lecture was, I'm certain, intense. The instructor used the physical model to elicit from the class: (1) a conceptualization of problem (forces, deflections); (2) an estimate of weights, forces, moments, etc.; (3) a solution which was found by volunteers who acted as official calculators for class.*" (Fall 1997)

> "*The interaction with the students was nothing short of outstanding. The students were all (50+) involved, interested and responsive as the engineering problem was defined, analyzed and solved. ... I know the students enjoyed the participatory approach, and I enjoyed it as well.*" (Fall 1997)

> "*This was a well-organized and fast-paced class, yet (he) was very effective at maintaining student participation through questions, discussions, and demonstrations. (He) exhibited excellent technical knowledge, his communication skills are terrific, and he was in touch with the student level of competence and progress.*" (Fall 1997)

The above teaching techniques and other aspects of the T^4E model have been presented to the Department of Civil and Environmental Engineering at Penn State and at a Penn State College of Engineering Teaching Workshop. In both audiences, the participants have mentioned that they particularly like the Board Notes. Said one colleague, "Having the board notes certainly increased the clarity and organization of what went to the chalk board .... The board notes freed me from having to think about where items in my notes would be placed on the chalk board because that was done ahead of time."

4. Final Observations and Conclusions

The methods and techniques discussed within this paper are certainly not the only ones available for effective teachers. However, for this author, they have provided a specific approach by which to interact with students and begin to understand their approach to the material. These techniques have also provided a directed avenue by which to interject the author's energy and enthusiasm for engineering into the classroom.

The T^4E model has been particularly helpful in all of these aspects. The well-defined structure (only a partial of which was discussed here) of the model provides significant flexibility for personal style. In many ways, it is a compendium of well established teaching principles. Its focus, however, is directed towards specific techniques of how to accomplish the effective (student-based) communication that is so highly desired. It is in this task-oriented approach that the author finds much value in the model.

Appendix

Table 1: SRTE Questions

Number	**Question**
A3	Rate the overall quality of this course.
A4	Rate the overall quality of the instructor.
B1	Rate the clarity of the instructor's explanations.
B2	Rate the the instructor's skill in maintaining a positive atmosphere for learning.
B3	Rate the adequacy of the instructor's knowledge of the subject matter.
B4	Rate the instructor's ability to convey his/her experiences with the subject matter.
B5	Rate the instructor in terms of his/her preparation for class.
B6	Rate the effectiveness of the instructor in demonstrating the significance of the subject matter.
B7	Rate the effectiveness of exams in testing understanding and not memorization.
B8	Rate the flexibility of teaching methods used to accomdate individual differences.
B9	Rate the effectiveness of the instructor's presentations.
B10	Rate the instructor's skill in encouraging students to think.

Table 2: Selected EFTE Questions

Number	**Question**
4	The method (or methods) of presenting information in class enhances my learning.
8	Testing methods are a fair representation of what we should learn from this course.
11	There is a good match between the major elements of instruction (objectives, lessons in class, and exams).
12	My overall rating of the course is very good.
13	The instructor is enthusiastic and interested in teaching this engineering course.
16	New concepts and solutions are clearly explained at a level students can comprehend.
17	The instructor effecitvely stimulated my intellectual curiosity about how to apply course material to engineering problems.
19	The instructor was always prepared for class and was concerned about his or her preparation.
20	My overall rating of this instructor is very favorable.
23	The instructor should continue to ask questions in the manner he does.
24	The instructor should continue to use the presentation style that he does.
25	The instructor should continue to implement boardwork the way he does.
30	Relative to other classes, I find this class: 1 = Boring; 2 = Seldom Interesting; 3 = Sometimes Interesting; 4 = Interesting half the time; 5 = Usually interesting; 6 = Interesting most of the time; or, 7 = Very interesting.

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