AC 2008-192: A TEXT FOR ENGINEERING EDUCATION IN THE 21ST CENTURY 1. OBJECTIVES AND OVERVIEW

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A TExT for Engineering Education in the 21st Century
1. Objectives and Overview

Abstract

Engineering education research continues to demonstrate that a growing variety of teaching methods are more effective than the time-honored lecture format. In addition, the engineering education literature provides a wealth of examples of the implementation of these more effective methods, along with data establishing their efficacy. Nonetheless, the standard lecture format remains in widespread use. This might be remedied by replacing the conventional textbook with a TExT (Toolkit for Exceptional Teaching) that integrates a comprehensive set of teaching tools with the content normally found in a textbook. A prototype TExT is being developed so that this hypothesis can be tested. The objectives of the TExT are enumerated, its components are identified, and their intended use is described in this overview of its on-going development. The use of the prototype TExT, at its current level of development, in teaching a senior-level undergraduate engineering course is also described.

Introduction

Teaching methods that involve and engage the students (e. g. active learning, collaborative learning, cooperative learning, problem-based learning, inquiry based learning, project based learning and case-based learning) have been studied and found to be more effective than traditional the lecture [1, 2]. Nonetheless, in 2001 the National Center for Education Statistics reported that 87.7% of engineering faculty used lectures as an instructional method in the classes they taught while only 5% indicated the use of methods other than lecture, seminar, lab or field work [3, 4]. The benefits and desirability of incorporating more effective teaching methods would appear to be obvious, raising the question why the traditional lecture format remains so predominant and how instructors who use this less effective teaching approach might be "won over" to using active learning in their classrooms.

Some (hopefully small) fraction of engineering instructors simply has no interest at all in the engineering education literature or in attending teaching workshops. It may not be worth the effort to even attempt to persuade this group of instructors to deviate from a traditional lecture format [5]. A second group of engineering instructors may have an interest in using more effective teaching methods, but at the same time may harbor reservations. Their reservations may include concerns about whether the methods really work, about how to implement them in a particular situation (large class, distance learners, etc.) or about whether the same amount of material can be "covered" as in a traditional lecture format [6-8]. The National Research Council has noted [9, 10] that one of the challenges here is informing faculty about research on effective teaching, and they have emphasized the need to create a community of scholars who can act as resources for doing so. The need to for this type of scholarly network is echoed in reports from Project Kaleidoscope[11] and from the National Academies [12].

There is a third group of engineering instructors, perhaps even the majority, who do not oppose the use of more effective teaching methods, and who desire to be good teachers, but who cling to the traditional lecture approach in their teaching. It is the belief of the present author that there are three primary reasons for this. The first is comfort and familiarity; the lecture format is the one that today's professors experienced when they were students, and it's the one they have employed in their own classes since then. The second factor is that faculty time must be divided between creative/research activities, teaching, and service. It is possible to be regarded as a good or excellent teacher while employing the standard lecture approach. A significant investment of time and effort is required to redesign a course in a manner that abandons that method and replaces it with more effective ones. If one is already recognized as a good teacher (and perhaps even if one is not so-recognized), the rewards, recognition and advancement that would result from investing this time are often smaller than if the time instead was expended on research and creative activity. The third factor is that readily available teaching materials (i. e. textbooks) do not include or provide teaching resources that would be needed to teach in formats other than the traditional lecture. There may be many, many additional teaching materials available (on the web, from the National Science Digital Library (NSDL), etc.), but it is left to the teacher to find them, determine how they might be fit into an effective teaching approach, change the nomenclature they use to match that of the course being taught, etc. etc.

It can be hypothesized that if implementing and teaching a course using proven methods like active learning [1, 13-17], team learning [18-20], problem based learning [21, 22], inquiry based experimentation [23, 24], contests/games [25], case studies [26, 27], etc. was just as easy as implementing the traditional lecture method and required a comparable commitment of the instructor's time, then a greater percentage of faculty would do so. One way to test this hypothesis is to redefine expectations for an engineering textbook in the 21[st] century. This paper introduces a prototype TExT (<u>T</u>oolkit for <u>Ex</u>ceptional <u>T</u>eaching) that is being developed for this purpose. The TExT expands upon the information transfer provided by current textbooks and integrates it with a comprehensive set of teaching tools and resources. The objective is to deliver an effective educational experience to engineering students, while simultaneously providing almost everything a teacher needs in order to implement effective teaching *without investing significantly more time than would be used in the traditional lecture method*. Indeed, most engineering professors are not trained educators; they are engineers. In other educational settings where it can be anticipated that the instructors will not be trained educators (e. g. nursery schools, Sunday schools, etc.), and in some cases where they are (primary school) it is common for publishers to include teaching materials for the instructors that integrate with the learning tools being used by the students.

This paper presents an overview of a TExT that is being developed for use in teaching an upper-division undergraduate course in chemical engineering, specifically reaction engineering. It is meant to be a prototype that could be replicated for most engineering course topics. That is, this paper will not discuss specific reaction engineering content, but instead will present a more general overview of the project along with its current status and some initial assessments of its use.

Objectives of the Prototype TExT

The first major objective of the TExT is to transform the classroom from a place for transferring information (via the traditional lecture) to a place for deeper learning. Importantly, the TExT does not eliminate information transfer via lecture; it simply moves it outside of the classroom. This is done by incorporating written information, as found in traditional textbook, and video presentations, such as currently found in a traditional classroom lecture. Some fraction of classroom time still must be used to ensure that the information transfer actually took place outside of the classroom, but the majority of classroom time thereby becomes available for other activities.

The second major objective of the TExT is to provide learning activities to be used in the classroom along with detailed lesson plans describing how to conduct these activities. To the maximum extent possible, this includes providing the resources necessary for conducting the in-class activity. In cases where the resources cannot be provided, the lesson plan includes a list of all the items the instructor will need in class along with an indication of those that must be obtained from a source external to the TExT. The key points of this objective are to ensure (a) that each activity is well designed as a student learning experience, (b) that implementation of each activity is straightforward and time-efficient and (c) that the associated lesson plan is sufficiently detailed to enable an instructor who is not familiar with the education literature to conduct the activity effectively and with minimal emotional discomfort.

The third major objective of the TExT is to provide tools, activities, etc. for continued independent learning outside the classroom. The methods for doing this include extending the in-class activities beyond class time in addition to methods like those used in traditional textbooks (homework problems).

The last major objective for the prototype TExT is to provide a comprehensive set of tested assessment tools. Two types of assessment are needed. One is the typical assessment of student learning and performance that is used in assigning grades. The other is assessment of the effectiveness of the individual learning activities as implemented by the instructor using the TExT.

(Once the prototype TExT has been completed, the next phase of this project will be to test the hypothesis offered in the introduction. Additional assessment instruments will then be needed to determine (a) whether faculty who use the TExT actually can implement active learning teaching methods in an amount of time comparable to implementation of traditional lectures and (b) how that affects learning by the students that they teach. These will be assessments ***of*** the TExT, ***not*** assessments that are ***included in*** the TExT.)

Components of the Prototype TExT

The prototype TExT is being simultaneously developed and used in a course on chemical kinetics and reaction engineering that the author has taught since 1986. The traditional lecture method was used for most of this period. In 2006, the lecture material from these past offerings was divided into "study units" that correspond, on average, to the information that was presented in ca. 20 minutes of a traditional lecture. These study units are the fundamental building blocks of the TExT.

For each study unit, the TExT provides the same kinds of things found in a typical textbook: (1) a written list of educational objectives, (2) a "required pre-class reading" containing the new information associated with that study unit, (3) a "required pre-class examples reading" illustrating the use of that information to solve engineering problems that are based upon the educational objectives, (4) computational and other tools that are needed in order to do so, and (5) solved and unsolved problems that can be used to learn and practice using the information to solve engineering problems.

For each study unit, the TExT additionally incorporates things commonly found in the traditional lecture. These take the form of video files that students can view on a computer, and they include (6) a “required pre-class lecture video” and (7) a “required pre-class examples video.” (In the prototype text these videos take the form of animated PowerPoint-type presentations that include both the visuals and the audio “lecture” that goes with them. An alternative possibility that is not being used in the prototype, would be to create videos of traditional lectures that would show the instructor as they lectured.)

It is worth noting that both the written materials and the video files for each study unit in the TExT are separated into one part that presents the facts and information and a separate part that provides examples and illustrations using that information. One advantage of this division is that the examples used in a study unit can be kept current much more easily. Another is that an instructor can easily “over-ride” a component when they choose simply by replacing or augmenting that one component. Students won’t be confused when the professor appears to tell them one thing while the book tells them something different because that part of the “book” can be easily replaced by the professor.

The components described so far are used primarily by the students, and it is intended that they have used them prior to coming to class. The next set of components is for use in class, primarily by the instructor. These include (8) a set of slides and notes, one set for each study unit, that can be used to review what the students should have read, watched and heard prior to class and to put it into context with respect to the entire course, (9) a set of instruments for assessing how well the students carried out their pre-class preparation or for motivating them to do so, and most importantly (10) a set of active learning tools with comprehensive lesson plans.

The TExT will eventually incorporate several different active learning tools for each study unit (many more than would be used in any single offering of the course). Most of the active learning tools that have been developed to date take the form of group learning activities, one-minute papers, games for learning, and role-playing object lessons. Yet to be added are activities using computer simulations for inquiry-based learning activities, sets of active learning tools that span multiple study units forming a case study approach, and others. Some of the active learning tools are structured so that the activity begins in class and then “spills over” into an independent learning activity or a homework assignment. As already described, each active learning tool includes the resources needed for the activity (as much as possible), and a detailed lesson plan for the instructor who is using the active learning tool

The final group of TExT components is typically used after class. This group includes (11) instruments for assessing student learning (such as exam problems, individual projects, group projects, etc. that can be used for grading purposes along with homework from component (5) above) and (12) instruments the instructor can use to assess how effectively they implemented the active learning tools that they chose to use in class.

The components of the TExT are summarized in the table below. One additional feature of the TExT can be mentioned at this point. Rubrics are used wherever possible. In particular, when examples are presented anywhere in the TExT, a rubric always accompanies the example indicating how it would have been graded if it had been given as an assignment. Also, every problem that is included in the TExT as a possible homework or exam problem also has a corresponding rubric included with the solution (only available to the instructor). In this way, students are given a feeling for how they will be graded prior to the actual event, and they can see what aspects of the solution are deemed most important.

Summary of TExT Components	
Number	Component (for each Study Unit)
1	Learning Objectives
2	Pre-Class Required Reading
3	Pre-Class Required Examples Reading
4	Computational and Other Relevant Tools
5	Additional Solved & Unsolved Examples
6	Pre-Class Required Lecture Video
7	Pre-Class Required Examples Video
8	In-Class Review Slides and Notes
9	Pre-Class Preparation Assessment Tools
10	Active Learning Tools with Lesson Plans
11	Student Learning Assessment Tools
12	In-Class Activity Assessment Tools

Students' Perspective of Learning using the TExT

Given the description of the TExT's objectives and components above, the way it is used may already be obvious. This section will attempt to present how the TExT is used from the students' perspective. For a typical class session, students would be assigned to read components (1) through (3) above, and they would be assigned to view components (6) and (7). They would be expected to have done so prior to class. For a 50-minute class session, two study units would normally be assigned. The intention is simple and straightforward: by the time the students arrive for class, they have already experienced what would have happened during a traditional lecture. When appropriate or effective, videos shot with a video camera (e. g. a demonstration shot in a laboratory) are also included in the pre-class assignment. One goal in providing multiple formats, (and varying the method of presentation within them) is to accommodate different learning preferences of students [28-30]. Another advantage is that the students can progress through the video "lectures" at their own pace, pausing and rewinding as much as they desire.

The pre-class materials and the written learning objectives that accompany them are geared toward desired student skills in the lower levels of the cognitive domain of Bloom's taxonomy [31]. That is to say, the pre-class resources stress knowledge, comprehension and simple, straightforward application of the information and ideas central to that study unit. This is also typically true of reading assignments and class time lectures in the traditional approach. The differences between using that method and a TExT begin to arise when the focus shifts to the higher levels of

Bloom's cognitive domain taxonomy. In classes taught using traditional lectures, students acquire the higher-level skills to apply the information, analyze, synthesize and evaluate when they attempt to solve homework problems or other tasks that have been assigned. (This presumes that the assigned homework necessitates such skills and isn't simply rote practice involving problems similar to those covered in class or in the textbook. This isn't always the case.) Thus, the higher-level learning occurs when the students are on their own time outside of class. When they are taught using the TExT, the lower-level information transfer has occurred before class. Class time is spent cultivating the higher levels skills, and it happens via active learning under the guidance and with the assistance of the professor.

When the TExT is being used, a typical class begins with a brief review or overview of the information that was presented in the assigned pre-class readings and videos. (The instructor can use component (8) for this.) This refreshes the students' memories and additionally affords them the opportunity to ask questions about any aspects of those materials that they didn't understand. It places the material in context with respect to the field or the overall course. Ideally, at this point, maybe ten minutes into the class, the students are at the same place they would have been at the end of class if a traditional lecture were being used. Hence, again ideally, the remaining majority of the class time can be used to actively engage the students. Before describing this, however, permit a brief digression.

The author used the developing TExT in teaching the first one-third of the course in 2006 and in teaching the first two-thirds of the course in 2007. Two observations that stand out from those experiences will be mentioned here. The first is that the students did not appear to be accustomed to coming to class prepared. This is believed to be a consequence of the predominance of courses that use the traditional lecture format. In those classes, pre-class readings might be assigned, but the students appear to take the view that the lecturer will tell them which part of the reading is important, so there isn't any need to read it all, especially before class. In addition, the students learn "through the grapevine" whether a given professor gives exams that draw from material other than what was presented in lecture. If the professor's reputation is that exams only include what was "covered" in class, many don't read the textbook at all. As a consequence, the author has found that it is essential to use quizzes and other motivational methods to coerce them to complete the pre-class assignments before class. This is especially true in the earlier meetings of the class.

The second, related observation was that there was a fraction of the students who were very, very difficult to motivate in this regard. As an illustration, at one point the quizzes to be used to assess whether the students had come to class prepared were repeatedly posted on the course web site several days prior to class. The nature of these quizzes was simply to see if the students could recall facts from the reading; they did not require any analysis or computation, simply recall. It was surprising to find students who did not pass these quizzes, even after it was pointed out to them that the quizzes were being posted ahead of time. That is, by checking the web site they could determine whether they were going to have a quiz that day, and they could see the quiz that was going to be used, and some still did not pass it! Indeed, the author is still pondering what other methods might be more effective in motivating these students.

Returning now from that digression, on some class days, the review of the pre-class materials might be followed by a short quiz that is designed to determine whether the students actually did the pre-class reading and watched the assigned video lectures. The instructor would use component (9) above for this purpose. The remainder of the class time is typically used to engage the students in one to three active learning activities that the instructor would select from the TExT, component (10) above. More often than not, a learning activity leads to one or more brief discourses by the professor that bring out a relevant point from the activity and/or lead into the next activity. When more than one activity is used in a class, they type of activity is normally varied. In some cases, the activities "roll over" into a homework assignment.

A few examples of simpler active learning tools will be offered here for illustration purposes. The collision theory of chemical reaction treats gases as if they are hard spheres and assumes that reactions are the result of collisions between the spheres. The author has used a simple active learning tool related to a required reading on collision theory in recent classes. A set of ping-pong balls is brought to class. The balls have been painted so that each ball has one hemisphere that is red and the other is white. The class is first divided into two groups that line up on opposite sides of the room. The first student in each line rolls their ping-pong ball attempting to collide with the other. This is repeated for each person in line, and the fraction of attempts leading to collision is recorded. To illustrate steric effects, it is next assumed that a reaction will only occur if the red side of one ball hits the red side of the other ball, and the activity is repeated. The class is then divided into three groups that attempt to create a simultaneous collision of three balls, and again results are recorded. The lesson plan that would be included with this active learning tool would include more detailed instructions on how to organize the activity, supplies necessary, etc. It would then include a number of questions that the instructor could use to initiate discussion. These questions would include noting differences between the activity and the collision theory (e. g. in the activity the motion of the balls is guided, in the theory it is random), the effect of steric constraints (like colors must collide) upon the probability of a successful collision and how that relates to the theory, the probability of simultaneous three-body collision and what are the implications for real reactions, and so forth.

Computational simulators can be used very effectively as active learning tools. The illustrative example given here is related to a required reading on the transient response of a reactor to a change in the inlet concentration of a tracer. This active learning tool would begin with a very brief video showing a stirred glass beaker with water flowing through it. Suddenly some red dye would be injected into the beaker, and the video would show how the red color slowly fades. The students would then be given access to a JAVA program that simulates this kind of reactor behavior. Working alone or in small groups, they would be asked to explore how the system responds to different changes in the system parameters (flow rate, reactor volume, whether dye is injected or added continuously, etc.) They would use the simulator to perform virtual experiments to study these effects. Several different lesson plans might accompany an activity like this. As one example, the students might first be asked to determine the shape of a plot of the reactor response. They would then be guided in using their response to postulate a mathematical relationship for it. They would next be led in quantifying the expression they generated by looking at limiting behavior (what happens initially, what happens after a long time, etc.). By the end of the activity, they would have arrived at the actual response equation. Finally, they would derive the equation and see that it agrees with the one they found experimentally. The lesson plan for this active learning tool would describe how the activity should be performed and then describe how the teacher could use the results to guide the class through the process just described. This is also a good example of an active learning tool that can be extended to become an independent learning tool. Once the students have used it in class, they can then be given assignments or suggestions for additional virtual experiments to perform.

Activities like these would constitute the remainder of the class meeting time. Following class, the students would typically work on additional problems that had been assigned for homework, components (4) and (5). If they felt the need or desire, they could also access additional solved and unsolved problems for additional practice. They might be asked to respond to some assessment instrument that the instructor was using to determine how effective the class was, component (12). Eventually their learning would be assessed for grading purposes via an exam, project, etc. that the instructor constructed using component (13) of the TExT.

One final advantage of the TExT is worth mentioning. Because the active learning tools and other components are all a part of the TExT, the nomenclature they use is exactly the same as that used in the readings and the video lectures. The instructor saves time not only because they don't have to search for a relevant or appropriate activity, but additionally they don't have to then spend time modifying that activity for consistency with their nomenclature, etc. This additionally contributes to reduced levels of student confusion arising from differences in nomenclature, etc.

Student Reaction to being Taught Using the Prototype TExT

Students in every engineering class at the author's institution fill out a course evaluation. The professor is not present when this is done. The evaluations have two parts, a set of multiple-choice questions and four open-ended questions. The latter consist of listing three things most liked about the course, three things most disliked about the course, listing three suggestions for improving the course and listing any other comments. Since the 2006 and 2007 offerings of the course used the TExT for part of the course and a traditional lecture format for the remainder, the written responses from these years provide useful qualitative assessment data. The students typically respond in phrases, so in some cases there is ambiguity in the meaning of their responses. For example, when students indicate the readings and video lectures as a like, it could mean they like the materials, but not the teaching methods, it could refer to the manner in which they were used, etc. Nonetheless, the results are quite positive.

In 2006 and 2007 a total of 43 student responses were received. There did not appear to be any differences between the two years with respect to the distribution of responses. The following points are particularly noteworthy.

- 19 responses listed the TExT materials (pre-class readings and videos) as an aspect of the course they liked while only one listed it as a dislike.
- 9 responses mentioned the active learning activities as a liked aspect; none listed it as a dislike.
- 17 responses suggested that the last part of the course (traditional lectures) should be taught the same way the first part was taught (TExT); 1 response suggested the opposite – that the course should be taught using a traditional lecture format.

- 5 responses listed the written materials as a like and the video materials as a dislike or vice versa.

There were no responses that expressed dissatisfaction with the TExT approach. There were positive responses about the teaching methods, for example “easy to learn,” and “great learning environment.”

Summary

This paper has suggested that a major barrier to the replacement of traditional lectures with teaching methods that are more effective is the time and effort it would impose upon an instructor who is not a teaching specialist along with uncertainty or discomfort about exactly how to implement such methods. It has further suggested that this barrier can be substantially reduced if the necessary teaching resources and lesson plans for using them are combined, in a uniform and integrated manner, with the items contained in conventional textbooks and college lectures. The resulting TExT (toolkit for exceptional teaching) would reduce the barrier for the non-specialist to implement more effective teaching methods and lead to increased use of superior teaching methods. In order to test this hypothesis, a prototype of such a TExT is being developed. This paper established objectives for the TExT, identified components that should be included in such a TExT and provided an overview of how the TExT is used. Subsequent papers in this series will provide more detailed consideration of individual components of the TExT, and their use. Once TExT development is completed, it will be used to test the hypothesis that if the textbook of the 20th century is replaced by TExTs in the 21st century, then a greater proportion of engineering courses will be taught using methods that are more effective than the traditional lecture.

1. Prince, M., *Does Active Learning Work? A Review of the Research.* J. Engr. Education, 2004. **93**(3): p. 223-231.
2. Prince, M., *The Many Faces of Inductive Teaching and Learning.* J. Coll. Sci. Teaching, R. M. Felder. **36**(5): p. 14.
3. Wirt, J., S. Choy, D. Gerald, S. Provasnik, P. Rooney, S. Watanabe, R. Tobin, and M. Glander, *The Condition of Education 2001*, B. Kridl and A. Livingston, Editors. 2001, National Center for Education Statistics, U. S. Dept. of Ed., Office of Educational Research and Improvement: Washington, DC. p. 309.
4. Bernold, L.E., *Paradigm Sifrt in Construction Education is Vital for the Future of Our Profession.* J. Construction Eng. Manag., 2005. **131**(5): p. 533-539.
5. Felder, R.M. and R. Brent, *FAQs. VI. Evaluating Teaching and Converting the Masses.* Chem. Eng. Ed., 2003. **37**(2): p. 106-107.
6. Felder, R.M. and R. Brent, *FAQs.* Chem. Eng. Ed., 1999. **31**(3): p. 32-33.
7. Felder, R.M. and R. Brent, *FAQs. II. (a) Active Learning vs. Covering the Syllabus; (b) Dealing with Large Classes.* Chem. Eng. Ed., 1999. **33**(4): p. 276-277.
8. Felder, R.M. and R. Brent, *FAQs. III. Groupwork in Distance Learning.* Chem. Eng. Ed., 2001. **35**(2): p. 102-103.
9. *Evaluating and Improving Undergraduate Teaching*. M.A. Fox and N. Hackerman, eds. The National Academies Press, Washington DC 2003 [Available from: http://www.nap.edu/books/0309072778/html].
10. *How Students Learn: History, Mathematics, and Science in the Classroom*. M.S. Donovan and J.D. Bransford, eds. The National Academies Press, Washington, DC 2005 [Available from: http://www.nap.edu/books/0309074339/html].
11. *Recommendations for Action in support of Undergraduate Science, Technology, Engineering and Mathematics*. eds. 2002 [Available from: http://www.pkal.org/documents/ReportonReports.pdf].

12. *Improving Undergraduate Instruction in Science, Technology, Engineering, and Mathematics: Report of a Workshop*. R.A. McCray, R.L. DeHaan, and J.A. Schuck, eds. The National Academies Press, Washington, DC 2003].
13. Felder, R.M., *It Goes Without Saying.* Chem. Eng. Ed., 1991. **25**(3): p. 132.
14. Dixon, A.G., W.M. Clark, and D. DiBiasio, *A project-based, spiral curriculum for introductory courses in ChE: Part 2. Implementation.* Chem. Eng. Ed., 2000. **34**(4): p. 296.
15. Demetry, C. and J.E. Groccia, *A comparative assessment of students' experiences in two Instructional formats of an introductory materials science course.* J. Eng. Education, 1997. **86**(3): p. 203.
16. Feldman, L.J. and R.J. Hofinger. *Active participation by sophomore students in the design of experiments*. in *Proceedings Frontiers in Education Conference*. 1997.
17. Van Dijk, L.A. and W.M.G. Jochems, *Changing a traditional lecturing approach into an interactive approach: Effects of interrupting the monologue in lectures.* Int. J. Eng. Education, 2002. **18**(3): p. 275.
18. Terenzini, P.T., A.F. Cabrera, C.L. Colbeck, J.M. Parente, and S.A. Bjorklundm, *Collaborative learning vs. lecture/discussion: Students' reported learning gains.* J. Eng. Education, 2001. **90**(1): p. 123.
19. Beaudoin, D.L. and D.F. Ollis, *A product and process engineering laboratory for freshmen.* J. Eng. Education, 1995. **84**(3): p. 279.
20. Masten, S., K.-C. Chen, J. Graulau, S.L. Kari, and K.-H. Lee, *A Web-based and group learning environment for introductory environmental engineering.* J. Eng. Education, 2002. **91**(1): p. 69.
21. Maskell, D.L. and P.J. Grabau, *A multidisciplinary cooperative problem-based learning approach to embedded systems design.* IEEE Trans. Education, 1998. **41**(2): p. 101.
22. Vandebona, U. and M.M. Attard, *A problem-based learning approach in a civil engineering curriculum.* World Trans. Eng. Tech. Education, 2002. **1**(1): p. 99.
23. Cyr, M., V. Miragila, T. Nocera, and C. Rogers, *A low-cost, innovative methodology for teaching engineering through experimentation.* J. Eng. Education, 1997. **86**(2): p. 167.
24. Buch, N.J. and T.E. Wolff, *Classroom teaching through inquiry.* J. Professional Issues Eng. Educ. Practice, 2000. **126**(3): p. 105.
25. Gregson, P.H. and T.A. Little, *Using contests to teach design to EE juniors.* IEEE Trans. Education, 1999. **42**(3): p. 229.
26. Angelides, D.C. and A. Poulopoulos, *Case studies and information technology in civil engineering learning.* J. Professional Issues Eng. Educ. Practice, 2000. **126**(3): p. 125.
27. Bequette, B.W., K.D. Schott, V. Prasad, V. Natarajan, and R.R. Rao, *Case study projects in an undergraduate process control course.* Chem. Eng. Ed., 1998. **32**(3): p. 214.
28. Felder, R.M. and L.K. Silverman, *Learning and Teaching Styles in Engineering Education.* Engineering Education, 1988. **78**(7): p. 674.
29. Buch, K. and C. Sena, *Accommodating diverse learning styles in the design and delivery of on-line learning experiences.* Int. J. Eng. Education, 2001. **17**(1): p. 93.
30. Hunkeler, D. and J.E. Sharp, *Assigning functional groups: The influence of group size, academic record, practical experience, and learning style.* J. Eng. Education, 1997. **86**(4): p. 321.
31. Bloom, B.S., *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain*. 1956, New York: David McKay Co.