WRITING, CRITICAL THINKING, AND ENGINEERING CURRICULA

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Abstract *- Recently, writing-across-the-curriculum and critical thinking approaches have gained favor in higher education. However, while these movements have sprouted and grown roots in colleges of arts and science across the country, they have found the ground less fertile in colleges of engineering. These movements certainly influenced recent changes in the philosophy and approach to the accreditation of engineering programs, manifest in ABET Engineering Criteria 2000. Several ABET program outcomes are difficult to achieve using traditional approaches to engineering education. For example, it seems particularly difficult to show that graduate engineers will have the broad education necessary to understand the impact of civil engineering solutions in a global and societal context, and knowledge of contemporary issues as they relate to engineering problems. We believe that there is much to be gained from broader application of the philosophies and techniques of these movements to the education of engineers. This paper presents examples of assignments that promote these goals.*

Index Terms - ABET EC 2000 outcomes, critical thinking, writing, writing-across-the-curriculum

INTRODUCTION

ABET Engineering Criteria 2000 (EC 2000) program outcomes require that graduating engineers are able to communicate effectively, understand the global and societal context of their work, are aware of contemporary issues, and are able to engage in lifelong learning [1]. Assignments involving writing and critical thinking will help satisfy some of the more intangible ABET outcomes. These outcomes are designed to improve the preparation of graduating engineers for professional practice.

This paper first reviews some of the literature describing the inclusion of writing and critical thinking in engineering curricula. Then, we provide examples of writing assignments involving critical thinking that are designed to support these outcomes. We have used all of the example assignments successfully in engineering classes. In some cases, the classes have been designated as "writing intensive" or its equivalent; in other cases, the assignments are simply included in a "regular" course. We illustrate through these examples how some of the more "difficult to show" ABET program outcomes might be addressed.

WRITING AND CRITICAL THINKING IN ENGINEERING EDUCATION

Over the last several decades, critical thinking and writing across the curriculum (WAC) have been emphasized increasingly in higher education. These movements have attracted interest from engineering educators, but anecdotal evidence suggests that opportunities exist to increase the use of these techniques in engineering programs.

Definitions of critical thinking in the literature vary. For the purposes of this paper, we define it as engagement with problems that requires identifying and questioning assumptions, integrating knowledge, and applying these assumptions and knowledge to solve a problem (see [2] for additional discussion and definitions). A key ingredient is that the students understand that the solution to the problem is not unique. Bean [2] defines seven ways to give critical thinking tasks to students. These include:

1. Problems presented as formal writing assignments,
2. Problems presented as thought-provokers for exploratory writing,
3. Problems presented as tasks for small group problem solving,
4. Problems presented as starters for inquiry-based class discussions,
5. Problems presented as think-on-your feet questions for in-class "cold calling,"
6. Problems presented as focusing questions for in-class debates, panel discussions, cases or fishbowls, and
7. Problems presented as practice exam questions.

Writing is central to the first two of these and implicit in several others.

So, why do we want engineers to write? First, significant evidence has been presented that writing actually improves learning, and as educators, we are obligated to take this evidence into account in designing our courses. Second, our engineering students will have to write extensively once they are employed.

Writing across the curriculum programs are well documented in the literature. In the case of many large universities, WAC programs exist at the university level, and core curricula university-wide may require a particular number of "writing intensive" courses. In some cases, colleges of engineering (within a university) have developed programs for all engineers. Other options include

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department-wide programs or a particular course within a department.

Types of writing include both writing-to-learn (WTL) and formal writing assignments. WTL assignments include journal entries, reading responses, etc. While these types of writing are used often in liberal arts and social science classes, their use in engineering is less frequent. Formal writing assignments are more characteristic of engineering courses, although these typically include lab reports and design project reports. Less common is a more standard term paper. When term papers are assigned, they generally require students to choose a topic, and in most cases the student receives little feedback from the professor until the paper is graded.

Often, one of the stated motivations for including writing in engineering curricula is to improve the communication skills of engineering graduates. Surveys of engineering employers consistently show that the employers consider communication skills important and that new graduates continue to demonstrate weaknesses in this area [3,4]. Institutions and departments have implemented a variety of efforts that can be categorized broadly as belonging to one (or more) of several different models or strategies. The options considered (many of which have been well-documented in the literature) include:

- Single course vs. Sequence of courses
- Required course(s) vs. Elective course(s)
- Engineering course(s) that include writing vs. Technical writing course(s)
- Course(s) taught by English or Communications Department Faculty vs. Course(s) taught by engineering faculty
- Course(s) established at department level vs. Course(s) established at college/division level vs. Course(s) established at institution level

All of the options listed above may be appropriate for a particular department or institution. In other words, in considering how to integrate communication and critical thinking skills into a curriculum, the faculty should examine the institution and department mission.

Strategies to encourage writing and critical thinking can be applied in any course structure. The engineering education literature presents many examples of strategies. For example,

- Randolph links writing across the curriculum with Bloom's taxonomy to promote "higher levels" of learning in an information systems class [5]. He has also linked specific assignments to particular learning styles in an attempt to accommodate different types of learners.
- A number of authors have described and/or documented positive results from "write-to-learn" assignments in engineering classes, particularly those that involved keeping a journal or a log [6,7,8,9,10,11].
- Boyd and Hassett describe a very basic method for incorporating some writing in engineering classes [12]. Their strategy is to provide the students with the assessment scheme and then give short assignments that describe paragraph by paragraph what the students should address. While the authors documented improvement over the course of a semester, there is no assessment of the lasting benefits – i.e., what happens when the students receive an assignment where they have to structure the answer themselves?
- Sharp et al. provide examples of four writing-oriented tasks that have been used in engineering classes, including developing instructions, keeping journals, and peer review [7].

In addition, we have found the guidelines and examples provided by Bean [2] for including meaningful writing assignments in courses extremely helpful. The book is written as a "how-to" guide for emphasizing writing and critical thinking in any discipline.

ABET Program Outcomes

ABET criteria for accrediting engineering programs prescribe eleven program outcomes [1]. These are commonly referred to as ABET outcomes (a) through (k). Several of these outcomes, in particular outcomes (f) through (j), are hard to achieve in a traditional compartmentalized engineering curriculum. As part of these outcomes, engineering programs must demonstrate that their graduates have:

(f) An understanding of professional and ethical responsibility,
(g) An ability to communicate effectively,
(h) The broad education necessary to understand the impact of engineering solutions in a global and societal context,
(i) A recognition of the need for and an ability to engage in life-long learning, and
(j) Knowledge of contemporary issues.

The development of critical thinking skills is essential if a student is to achieve these outcomes. Furthermore, since writing can be a process of thinking critically and a means for communicating the results, writing in an engineering curriculum can provide the mechanism for achieving the ABET outcomes mentioned above.

We do not believe that a typical traditional approach, where an engineering student takes a technical writing class, a speech class, and random social science and humanities electives is a particularly good approach to achieving these outcomes. In our experiences with engineering education, the technical writing course may be taught by an English instructor with little interest in engineering. The student may to be asked to write a formal report about "something," with little importance given to what the "something" should be. Our experiences have also included listening to many students complain about the lack of value of technical

writing classes for developing effective communication skills.

The point of this discussion is that good writing abilities are not independent of subject. One must write about something. Someone who can write well about psychology, for example, may not be able to write well about engineering. Further, engineering students, who may have little interest in writing about non-engineering topics, or in writing as an academic field of study, may write very enthusiastically about engineering topics.

If we define "writing effectively" as the ability to produce discipline specific arguments, the literature provides support for the claim that writing produced in WAC science/engineering classes is better preparation for an engineering student than writing produced in technical writing classes. Rivard [13] reviewed literature related to writing to learn in science and indicated that drawing conclusions is difficult because few well-designed studies in classroom environments have been completed. However, based on the review of literature conducted, Rivard [13] concludes that writing can be employed to enhance science learning. In contrast, Scanlon and Coon [14] surveyed technical writing teachers concerning their attitudes regarding content of technical writing courses. They indicate that those surveyed suggested traditional teaching approaches (grammar, spelling, outlining), as well as word processing, graphics, ethics, and document design were the most important aspects of these courses. We do not mean to imply that technical writing courses have no place in an engineering curriculum, but we do believe that writing is taught much more effectively if engineering students are required to write in engineering courses.

Earlier, we listed seven types of critical thinking tasks after Bean [2]. All of these can be used to develop students who meet the "difficult to achieve" ABET outcomes (f) through (j) mentioned earlier. We have implemented several of these strategies for developing critical thinking skills in our engineering courses. The next section of this paper provides examples of writing assignments that are intended to develop critical thinking skills. Table 1 shows the ABET outcomes addressed and the type of critical thinking task, as defined by Bean.

EXAMPLE ENGINEERING WRITING ASSIGNMENTS

We have used the assignments presented here in courses ranging from first semester freshman orientation classes to senior electives. All of these assignments contribute to the students' understanding of the technical material in the class. Many require the students to expand their knowledge of contemporary issues and to think about the impact of engineering solutions in a global and societal context. Engineering students generally greet the assignments with enthusiasm because they are about "real world" engineering. Although the following examples are writing assignments, most could be revised easily to be presentation assignments. The actual text of the assignments appears in italics, while explanation appears in normal type.

TABLE I
MAP OF WRITING ASSIGNMENTS WITH BEAN [2] CRITICAL THINKING TASK AND ABET OUTCOMES

Writing Assignment	Bean Critical Thinking Task	ABET Outcome
1	1	(f) (g) (i) (j)
2	1	(f) (g)
3	1	(f) (g)
4	1	(f) (g)
5	1	(f) (g) (h) (j)
6	2	(f) (g) (h) (i) (j)
7	2	(f) (g) (h) (i) (j)
8	2	(f) (g) (h) (i) (j)
9	1	(f) (g)
10	2	(f) (g) (j)

Throw Out the Traditional Engineering Lab Report

A traditional engineering curriculum includes several laboratory classes. These classes usually require the traditional laboratory report. Students hate them! Engineers are unlikely to ever have to write one. Many students will prepare the report while looking at last semester's. One student's "A" report and another's will not differ significantly.

The following writing assignments were used in a required soil mechanics course in place of the traditional lab report. Students still completed the laboratory exercises and analyzed, processed, and presented the results. The difference here is that students are asked to apply these results. These assignments require more critical thought, and student submissions vary both in content and quality much more than with the traditional lab report.

1. **Subsurface Exploration and Soil Sampling Plan for Proposed Municipal Waste Landfill (500 words)**

   For the county you have been assigned, pick a potential location for a municipal solid waste (MSW) landfill. When developed, the landfill will receive 500 tons per day of MSW. The proposed disposal area will cover 100 acres when the landfill is completed. You must write a letter proposal to the owner in which you detail the preliminary site exploration program. With this letter proposal, you must (1) satisfy the requirements for a preliminary site investigation as stated in the Missouri DNR regulations (DNR 1997) and (2) appease the owner so that he awards your firm the project, i.e., keep the costs down!

   To begin this assignment, locate the Missouri DNR requirements for a preliminary site investigation and review them. Also review the "Guidance for Conducting and Reporting Detailed Geologic and Hydrologic Investigations at a Proposed Solid-Waste Disposal Area" by the DNR. Select a site within your

assigned county. Obtain whatever information you can about the site. A good source for preliminary information is the County Soil Survey prepared by the Soil Conservation Service (SCS) of the US National Resource Conservation Service (NRCS).

2. **Analysis of On-Site Soil for Suitability for Use as a Compacted Clay Liner (2000 words)**

   A sample of the on-site soil for the proposed MSW landfill has been obtained. You performed several geotechnical index tests (water content, specific gravity, grain size and Atterberg limits) on the soil in the laboratory. Given the results (which are limited), you must do your best to analyze the soil's suitability for use as the compacted clay liner in the proposed landfill.

   Check the Missouri-DNR regulations (Rules of DNR Div 80 – Solid Waste Mgmt, Chapter 3 – Sanitary Landfill, 10 CSR 80-3.010) for the soil suitability criteria for a compacted clay liner (CCL). Compare your results to the required specifications (a table works well here). In your conclusions, you must recommend for or against using this soil for the CCL. If you recommend against using the soil, you should suggest some potential alternatives to the client.

3. **Settlement Analysis of Foundation Soils Beneath the Proposed Landfill (2500 words)**

   The Missouri DNR permit reviewer has raised a critical issue regarding the proposed MSW landfill site. The reviewer notes that the natural soil lying beneath the proposed landfill is compressible. The heavy loads from the completed fill could result in compression of the underlying soil, leading to settlement and adverse impacts on the compacted clay liner (CCL) and the leachate collection system (LCS). The reviewer suspends review of the permit application until she receives a detailed engineering analysis regarding the possible settlement of the underlying soils due to the weight of the proposed fill and its impacts on the compacted clay liner and leachate collection system.

   You should perform a settlement analysis of the foundation soil for the proposed MSW landfill. An undisturbed sample of the soil was obtained during the site exploration, and a consolidation test was performed on the material in the laboratory. You should have the results from your lab class. Use the results of the consolidation test to estimate the amount of settlement the overlying compacted clay liner and leachate collection system can be expected to undergo. Prepare an analysis of the impacts of the settlement on the compacted clay liner and the leachate collection system.

   The proposed landfill will have a completed fill thickness of 300 to 350 feet. The fill is municipal solid waste plus intervening layers of soil used as daily cover and a soil cover on the completed surface. A typical total unit weight for very well compacted MSW is 1500 lb/yd^3. Properties of the underlying compressible soil are available from your consolidation laboratory. For calculation purposes, you may assume the entire thickness of fill is placed at one time.

4. **Peer Review Memo: Settlement Analysis of Foundation Soils Beneath the Proposed Landfill (500 words)**

   You have been asked to peer review an engineering report that is about to be sent to the permit reviewer at Missouri DNR Office of Solid Waste (Writing Assignment #4). You should read the report, mark and make comments on the report itself, and prepare a list of comments concerning the report.

   The design review memo should be addressed to the author of the engineering report and summarize the comments of the peer review engineer. The review comments should be substantive, going well beyond checking for spelling and punctuation errors. The memo should be professional, and criticism should be constructive in nature.

   Two copies of the peer review memo should be made. One copy, along with the marked draft report, will be given to the engineering report author to aid in the revision of the report. One copy of the peer review will be given to the instructor to grade.

Students can also be asked to perform laboratory testing in a design class, which by nature requires one or more written reports. The following assignment was given in a junior level, project-oriented design class.

5. **Design Project Report**

   Project Location: Northampton County, PA

   Problem/Client: Citizens have complained to the Pennsylvania Department of Environmental Protection (DEP) that the water in the Schoeneck Creek appears to be exceptionally "dirty," especially when compared with the nearby Bushkill Creek. The DEP has asked that you address the complaint.

   Task: Determine the source and magnitude of the problem, and design a treatment facility. You will perform several laboratory tests to determine the design parameters. Your final design and supporting details will be documented in a team design report.

Impact and Knowledge, Professionalism and Ethics

The following writing assignments are examples of how the impact of engineering solutions in global and societal context and knowledge of contemporary issues can be integrated into engineering coursework. These assignments also incorporate considerations of what it means to be a professional, and what it means to act ethically.

The next assignment was used in a freshman orientation course. The assignment deals directly with hydrology and could easily be adapted to a hydrology course; however, it could also be used in a separate ethics course.

6. **Micro-theme – Should dams be removed? (250 words)**

   ABET (Accreditation Board for Engineering and Technology) requires that graduate engineers have the

"broad education necessary to understand the impact of engineering solutions in a global and societal context". The following micro-theme assignment is designed to illustrate the importance of this statement. Attached to this assignment is a copy of a recent article published in the April 2001 issue of National Geographic. The article is entitled Columbia River – Forever Damned? For this micro-theme assignment answer the following question. Should the existing dams on the lower Snake River be removed? Use the 250-word micro-theme to articulate and defend your answer to this question.

The next assignment was used in a sophomore strength of materials course, shortly after September 11, 2002. A slightly different version was also used in the freshman orientation course.

7. **Essay – Implications of the World Trade Center Collapse (500 words)**

   As you all know, on September 11, 2001, terrorists crashed two airliners into the World Trade Center Towers in New York. Subsequently, these towers collapsed. When engineered structures fail, it is the role of the engineering community to examine these failures, scrutinize, and possibly revise our current approaches to design in order to hopefully prevent such failures in the future. Sometimes this is possible. For example, the failure of the Tacoma Narrows suspension bridge and subsequent engineering analysis has significantly influenced how we currently design suspension bridges. Sometimes it is not. For example, the events of World War II caused much destruction around the world, but when buildings were rebuilt they were not designed to withstand the impacts of bombs and artillery shells.

   We have all seen the failure of the WTC towers on TV. The website http://www.civil.usyd.edu.au/wtc.htm contains some engineers expert opinions regarding the failure of the towers. The construction periodical Engineering News Record has published several engineering perspective articles that are available at www.enr.com.

   Your assignment is to combine your personal observations with the information available at the websites mentioned above and prepare a 500-word essay concerning the future implications of the WTC tower collapses on the design, construction, and operation of skyscrapers. You essay should answer the following. Why did the towers collapse? Were the towers design to withstand the event that caused their collapse? What event were the towers designed for? How well did the towers perform structurally? As new skyscrapers are built, what event should they be designed to withstand?

The next assignment can be given in any class with reading assignments. It is particularly effective at encouraging students to prepare for lecture or discussion by not only reading carefully but also by reflecting on the subject and connecting it to their own experiences. It is adapted from [2].

8. **Writing to Learn – Summarize and Respond to Readings**

   Task: For each class with a reading assignment, you will write

   - *a summary of main points from the reading, and*
   - *a brief response to the reading, i.e., your own thoughts.*

   Purpose: This informal exercise is intended to help you read more effectively, both to develop a better understanding of what you have read and to think about how it applies to you. You should be able to do your summary as you read. The summary will help you understand the structure and details of the author's argument. It will also help you later in the semester to recall what you read (like when you're studying for the final exam!). The response will help you connect the reading to what you already know and prepare you for discussion.

   Procedure: Your summary can take whatever form you find most effective: paragraphs, an outline, a flow chart, bullets, or a list. Restate the main points of the reading in your own words. After the summary, write a brief response to the reading – this should be your own reflections or reactions. Again, use whatever format you prefer. You may want to do one or more of the following: refute, question, believe, doubt, analyze, relate your own experience, etc. Bring your written summary and response to class – your professor will periodically collect and skim them, looking for evidence of effort and thought.

The following examples represent short write-to-learn assignments given in a transportation engineering class.

9. **Writing to Learn – Compare/Contrast, Describe, etc.**

   a) For each of the categories discussed in Chapter 6 (pedestrians, transit and rail passengers, automobile drivers, and air transport passengers), discuss two of the primary factors that influence facility design.

   b) Use what you learned about traffic control in Chapter 5 and about human factors in Chapter 6 to discuss how human factors affect the operation of air, rail, and marine transportation.

The following assignment was used in an introduction to construction management class. Although it was not required, many students researched the Hyatt Regency collapse further and used the information obtained to support their answer to the question posed.

10. **Position Micro-theme – The Kansas City Hyatt Regency Walkway Collapse (250 words)**

    Two walkways, one above the other, along one wall of a large atrium were to be supported by welded box beams, which in turn were held up along the atrium side by long rods extending from the ceiling. Because of perceived difficulties in constructing the design, a modification using two shorter rods to replace each

long rod was proposed and approved. Schinzinger and Martin [15] describe this design modification. The result was an overload in the beam/rod/nut connection at the upper walkway. This failure caused a final death toll of 114 with 200 injured. Later it was found that the design change had been stamped "approved" but not checked.

Owners of a corporation have the advantages of limited liability for corporate debt or obligations. Today, some would hold individual persons responsible for the actions of the corporation, while others would find it appropriate to only to hold the corporation as an entity responsible. Legally, an individual can be declared guilty (and subject to criminal prosecution) and a corporation can be held liable (subject to monetary penalties) for the same harmful action. Let's suppose that the contractor and AE for the Hyatt-Regency were corporations. Take and defend, using about 250 words, one of the following positions,

1. *The AE corporation is solely liable for the damages due to the collapse of the Hyatt-Regency walkways.*
2. *The AE and contractor corporations are jointly liable for the damages due to the collapse of the Hyatt-Regency walkways, but none of either corporation's employees are guilty of criminal acts.*
3. *The AE and contractor corporations are jointly liable for the damages due to the collapse of the Hyatt-Regency walkways, and those employees responsible for "approving" the modification are guilty of criminal acts.*

CONCLUSION

ABET outcomes that require graduating engineers to have an ability to communicate effectively, the broad education necessary to understand the impact of engineering solutions in global and societal context, knowledge of contemporary issues, and an ability to engage in lifelong learning present challenges to the traditional compartmentalized engineering curriculum. In response to these challenges, we have applied the pedagogical principles that are central to the writing-across-the-curriculum movement. Writing-across-the-curriculum and critical thinking have gained favor in higher education, but they have not been applied broadly in engineering. We have shown, using example assignments, how these principles can be applied to better educate engineers with respect to these "difficult to achieve" ABET outcomes.

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