2006-2175: INTEGRATING WRITING TO PROVIDE CONTEXT FOR TEACHING THE ENGINEERING DESIGN PROCESS

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Integrating Writing to Provide Context for Teaching the Engineering Design Process

Introduction

"Fundamentals of Environmental Engineering" is a junior course taught in the Civil Engineering department at New Mexico State University. General course objectives are to learn and apply the engineering design process and develop and apply skills used by successful practicing professional engineers, including critical (reflective) thinking, communication, and documentation. This course teaches the fundamental civil-environmental engineering principles for design of conventional domestic water treatment and wastewater treatment systems. One of the primary learning objectives of the course is for students to be able to apply fundamental civil-environmental engineering principles and perform fundamental calculations for designing water treatment (physical-chemical treatment) and wastewater treatment (physical and biological treatment) systems. Design problems are used to demonstrate application of these principles and to create opportunities to comprehend and analyze conventional treatment alternatives. The depth to which the topics are covered is intended to develop comprehension of theories and concepts and analytical techniques required to successfully complete the design analysis and documentation for a facility preliminary engineering report as typically performed by a professional consulting engineering firm. The course builds on knowledge acquired in two pre-requisite courses, "Environmental Science" and "Introduction to Fluid Mechanics," and develops new skills which are specifically applicable to the department's capstone design classes. Through writing assignments, students develop written communication skills as well as a process for thinking through and solving civil-environmental engineering problems. Writing assignments are used to create a practical context that deepens their understanding and comprehension of the content area. The sequence of assignments progressively advances students from solving single solution problems to more complex open-ended problems that more closely resemble the engineering design process.

Developing Context for Engineering Practice

A program goal of the civil engineering department is to guide the student's development as a future professional engineer (PE). Meeting this goal is best facilitated by providing a context in which the students perform their work. The context in the "Fundamentals of Environmental Engineering" is created through designing a drinking water system for a local community. The foundation of this context includes: 1) General background – engineering design process, code of ethics, and Safe Drinking Water Act (SDWA), 2) Client/audience awareness – characterization of the municipality's future population and water demand, and 3) Technical analysis – water treatment unit operations theories and concepts, solving single solution problems, and identifying design parameters and criteria. The focal point which integrates these three components is a water treatment plant design project. The outcomes that are realized through this approach are accomplished by developing a preliminary engineering report (PER) which documents the results of the formal engineering design assignment. The outcomes that students realize include: 1) participating in team work, 2) developing effective written communication skills, 3) experiencing open-ended problem solving, and 4) developing technical competence and confidence. This process for creating the context and the outcomes are summarized in Figure 1.

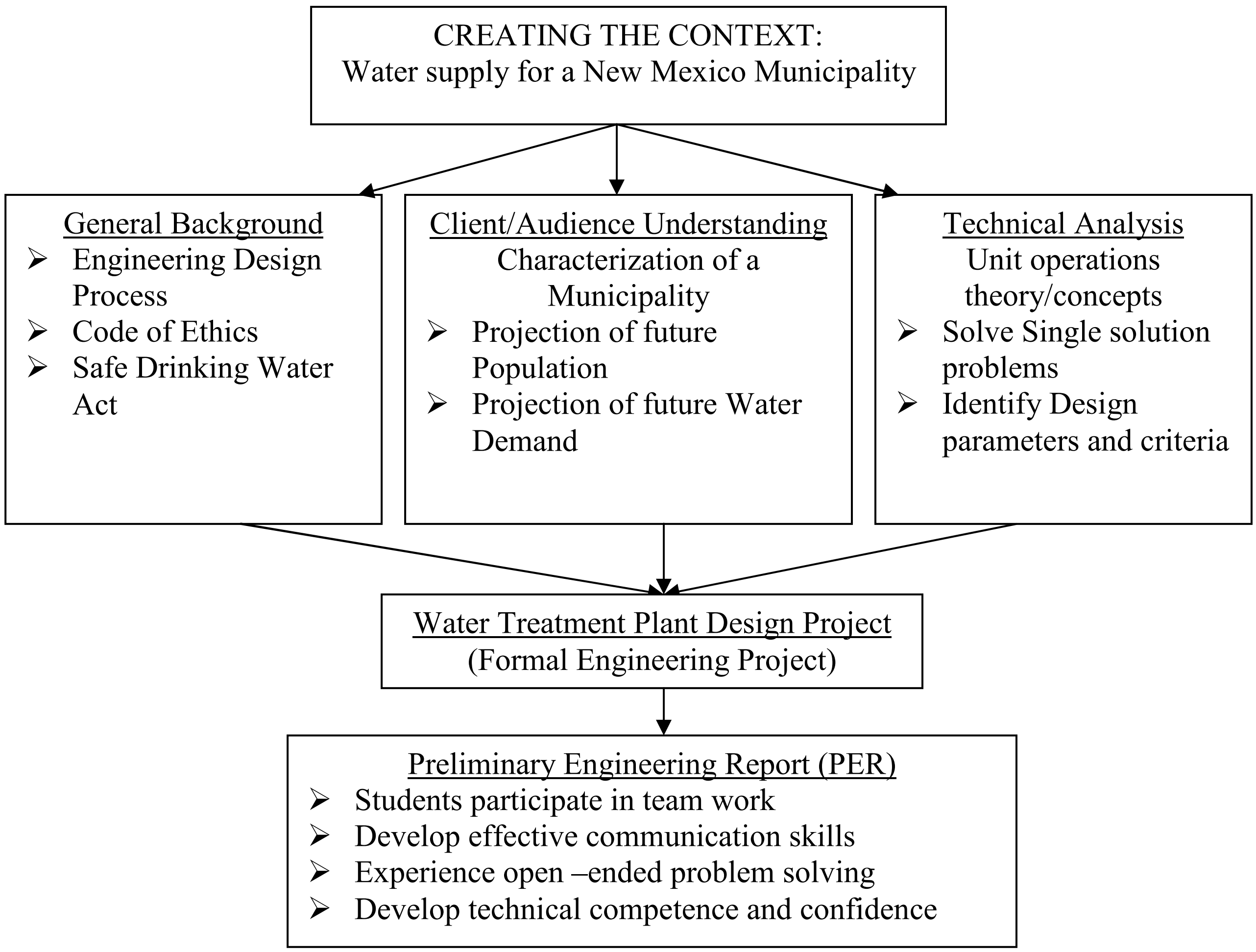

Figure 1. Developing Context for Engineering Practice.

Course Assignments

Students are provided a foundational understanding of the engineering design process by first identifying and describing the steps involved in a typical civil engineering project. An important component of this teaching is the integration of the civil engineering code of ethics within the design process. National and state regulations required under the Safe Drinking Water Act (SDWA) are also introduced, providing students with background for the assignments. Using an open-ended, team-based project approach, design principles, the design process of water treatment, and documentation practices are built on these foundational course elements. In the class assignment, students identify a city in New Mexico, characterize the city's population growth and water use histories, and summarize an analysis of both characteristics in an engineering report addressed to city engineers and planners.

The theories and design criteria of four basic water treatment technologies are taught sequentially. For each technology, students solve well-defined single-solution problems and write a summary statement of design objectives, parameters, and criteria. The final assignment is to design the four unit operations of the treatment plant, prepare preliminary engineering drawings of each unit operation, as well as a layout of the entire water treatment facility that shows integration of the individual unit operations. The design work is bound as a PER containing: 1) a letter of transmittal, 2) an executive summary of the design, and 3) an engineering report summarizing population and water use histories, alignment with SDWA requirements, and a summary and persuasive justification for technical decisions.

Engineering Design Process. The foundation of the class is an understanding of the engineering design process. The engineering design process taught to the students involves the following stages[1]:
1) Identify the problem, 2) Define the working criteria/goals, 3) Research and gather data, 4) Brainstorm/Generate creative ideas, 5) Analyze potential solutions, 6) Develop and test models, 7) Make the decision, 8) Communicate and specify details of the design, 9) Implement and commercialize or construct, and 10) Perform post-implementation review and assessment. This foundation is developed through an assignment which requires identifying and describing the steps involved in an actual civil engineering design project. This development is documented in a definition-type report which incorporates the civil engineering code of ethics with the design process. Teams of two students read an article from ASCE magazine describing a case study of an environmental engineering project. The case study provides the students the opportunity to identify, analyze, and understand the steps of the engineering design process. This exercise is also intended to help students understand the critical thinking skills an engineer applies in professional practice. For all engineering problems, there are fundamental questions that can be effectively addressed through application of the design process. The process begins with understanding the original problem, researching the problem, gathering information, developing a partial solution and completing the solution through successive cycles of actions as illustrated in Figure 2.

Population Projection**.** Design principles and the design process of water treatment and documentation of the process are built on the foundation of the engineering design process and are taught through an open-ended, team-based project approach. The project begins with assigning the class a municipality in New Mexico for characterizing the city's population growth, water use history, and future water demand. The report consists of a cover letter to the city engineers, an executive summary, followed by a comprehensive report containing the city characterization (historical, geological, community, industrial sectors), a twenty year population projection developed from census data and different growth characterization models, water resources available, present source of water supply and conservation practices, future water demands, and capacities for a new treatment facility. The report also discusses the national and state level regulations and policies required under the Safe Drinking Water Act (SDWA)[2].

Students are required to schedule a consultation with the writing center in the English department to receive a review of their report.

An evaluation heuristic[3] used by the graduate teaching assistant to grade the reports is provided to the students. Evaluation criteria include the following components: 1) Consideration of audience - specifying the client and clearly addressing all the client's needs, 2) Quality of solution - clear description of the problem and evaluation of the proposed solution with a persuasive argument, 3) Rigor of engineering analysis - relevant data, background and research pertinent to the problem, methods, calculations, analysis, and conclusions based on evidence, 4) Organization and focus - effectively organized, engaging and easily followed, 5) Clarity and coherence - flow in thought, transitions, graphical presentations, grammar/mechanics, and 6) Professional appearance - a consistent professional format. The first three components address the technical/engineering content and the remaining components address effective communication and professional appearance.

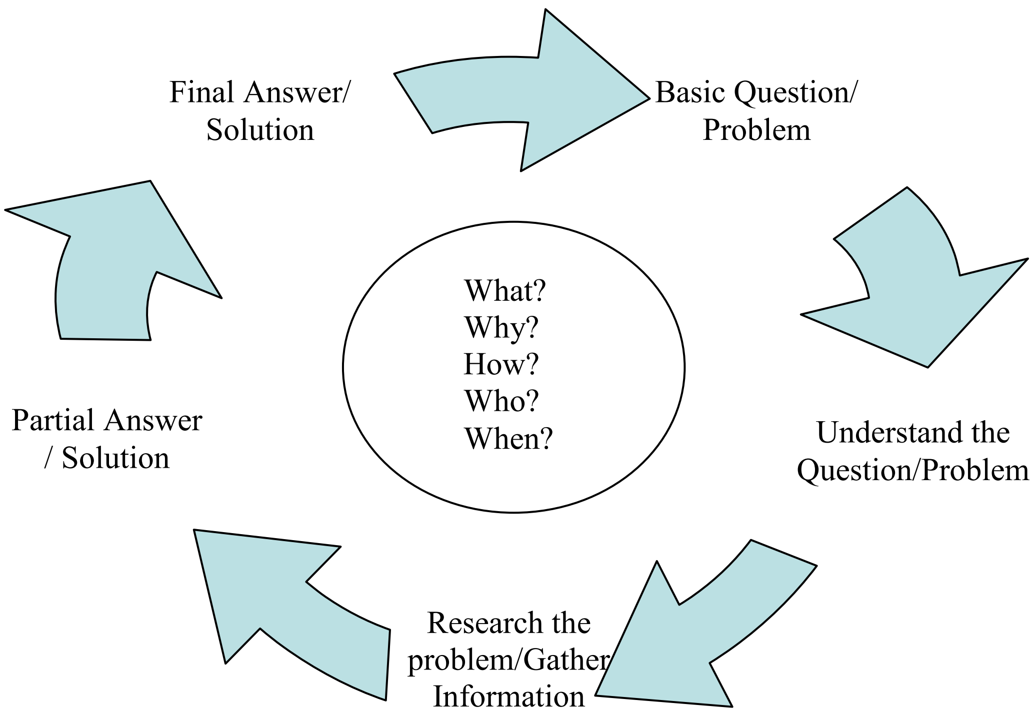

Figure 2. Critical Thinking Path for Engineering Analysis and Design.

Unit Operations Theory and Concepts. A traditional, conventional, surface water treatment process is taught to the class. The treatment train consists of four basic unit operations which include rapid mix, flocculation, sedimentation, and rapid sand filtration. The theories and design criteria of four basic water treatment technologies are taught in a sequential fashion. At each technology stage the students solve well defined, single solution problems related to each stage of treatment. At each stage each design team also writes a summary statement of design objectives, parameters, and criteria which match the city's water treatment plant. The first two design statements are written based on assignments describing the requirements of the documentation. The last two design statements are written without a guiding assignment giving students the opportunity to transfer the skills they learned in writing the first two design statements. The students are instructed to use the design statements as an internal document (internal to their hypothetical engineering firm) as a checklist of design parameters and criteria that will be applied when they design the unit operation for the city's water treatment plant.

Preliminary Engineering (Design) Report (PER). The final assignment is to design the four unit components of the treatment plant, prepare preliminary engineering drawings of each unit operation, as well as a layout of the entire water treatment facility which shows the integration of the individual unit operations into a single treatment plant. The design work is bound as a preliminary engineering report (PER) which includes the following three components: 1) a letter of transmittal to the city engineering staff, 2) an executive summary of the design, and 3) an engineering report summarizing the population and water use histories of the city, the alignment of their design with national and state level requirements of the SDWA, and a summary and persuasive justification for the decisions made in their technical design. The report includes an appendix which documents the design calculations and preliminary engineering drawings of individual unit operations. A summary of the design outcomes for individual unit operations is presented at the beginning of design calculations for each treatment stage. This is one way the students display the confidence of their design work. The PER is evaluated using the same criteria that has been discussed for the population projection assignment.

Results and Discussion

The course requires students to perform at a variety of cognitive levels as classified by Bloom's taxonomy[4]. In engineering practice, especially in the engineering design process, higher–order thinking is required. Too often junior engineering students are accustomed to learning material at levels 1 through 3 on Bloom's taxonomy scale (knowledge, comprehension, and application). The assignments in this course are created to facilitate student development as a future professional engineer by working at the six cognitive levels of Bloom's taxonomy. These assignments lead to progressive, step-by step growth in the students learning from level 1 to level 6. By the end of the course the students are learning and working at the highest level on Bloom's scale. Table 1 summarizes the Bloom classification for the various assignments.

The course is also assessed for fulfillment of ABET[5] (Accreditation Board for Engineering Technology) criteria and outcomes. A comparison of the criterion 3a-k which is achieved through the assignments is summarized in Table 2. Teamwork during the course provides first hand experience to the students in conducting research to obtain pertinent information on the municipality they're studying, analyzing the information obtained through the research, developing solutions to the preliminary design stages, and justifying their solutions. The result of meeting these criteria leads to a progressive development in working at level 4 to 6 on Bloom's taxonomy scale.

The instructors of this course emphasize that students think critically by developing open ended solutions and making decisions, and using evidence to make a persuasive argument justifying their decisions in a written document. Importance is given to writing so that the students learn to complement their analytical work with persuasive engineering reports that are professional in

Table 1. Assignment Classification Based on Bloom's Taxonomy.

Assignment	Level†					
Description	1	2	3	4	5	6
1) Engineering design process	√	√	√			
2) Population Projection/Water Demands	√	√	√	√		
3) Single solution problems	√	√	√	√		
4) Design statements/summary	√	√	√	√		
5) PER of Water Treatment Facility	√	√	√	√	√	√

†1. Knowledge (list, recite, reproduce), 2. Comprehension (explain, paraphrase), 3. Application (calculate, solve, determine, apply), 4. Analysis (classify, predict, model, derive, interpret), 5. Synthesis (propose, create, invent, design, improve), 6.Evaluation (judge, select, critique, justify, optimize)[4].

Table 2. ABET Criterion 3a-k Outcomes Addressed Through Assignments.

Assignment	*ABET outcomes**										
Description	*3a*	*3b*	*3c*	*3d*	*3e*	*3f*	*3g*	*3h*	*3i*	*3j*	*3k*
1)Engineering Design Process	√	√		√		√	√				
2) Population Projection/ Water Demands	√	√			√	√	√				√
3) Single Solution Homework Problems	√				√						
4) Design Statements/Summary	√		√	√	√		√				
5) PER of Water Treatment Facility	√	√	√	√	√	√	√				√

*Outcome 3a:an ability to apply knowledge of mathematics, science, and engineering; 3b:an ability to design and conduct experiments, as well as to analyze and interpret data; 3c:an ability to design a system, component, or process to meet desired needs within realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability; 3d: an ability to function on multidisciplinary teams; 3e:an ability to identify, formulate, and solve engineering problem;, 3f:an understanding of professional and ethical responsibility; 3g: an ability to communicate effectively; 3h: the broad education necessary to understand impact of engineering solutions in a global, economic, environmental, and societal context; 3i: a recognition of the need for, and an ability to engage in lifelong learning; 3j: a knowledge of contemporary issues; 3k: an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

content and appearance. At this stage in their education students don't appreciate or place value on the need for an engineer to have effective written communication skills; their primary objective is to excel in the analytical skills. This objective is understandable because their freshmen through junior courses typically emphasize analysis skills over written communication of the results of their work. In this course the students are required to excel in both areas. Table

3 shows a summary of the value assigned to writing in the course compared to the value assigned to the analytical requirements. The distribution of the work shows that 23% of the student's grade is attained though their written work. Other junior-level courses, excluding laboratory-based courses, that emphasize development of analytical skills may only assign 0-10% of the grade to writing efforts.

Table 3. Value of Writing Incorporated into Assignments.

Assignment	Points	
Description of the task	Writing	Analytical
1) Quizzes		150
2) Engineering design process	50	
3) Population projection/water demand	50	
4) Single solution problems		150
5) Design statements/summary	20	
6) Water/ Wastewater treatment exams		200
7) PER of Water Treatment Facility	50	50
Sub-total	170	550
Total	720	

Percentage of writing assignments in total points ~ 23 %

The writing across the curriculum (WAC)[6] approach is implemented to achieve higher levels of learning according to Bloom's taxonomy. This approach utilizes writing as a tool by which the individual creates meaning from experience, i.e., context. The instructors and teaching assistants (TAs) who practice this approach are trained through an official WAC seminar organized by the English department at New Mexico State University. The WAC seminar is focused on improving the instructor's and TA's ability to guide the student's thinking through well constructed writing assignments that align with a course's learning objectives. This outcome is accomplished by WAC instructors mentoring the seminar attendees on creating, implementing, and evaluating written assignments. Through WAC the understanding of good writing methods is transferred from the WAC instructors to the seminar attendees who in turn transfer these methods to their students in the class environment.

The fundamental importance of this training is exemplified in the benefit to the students. The assignments that are used in CE 356 are based on individual and collaborative learning through individual and team-based activities. The assignments include brainstorming exercises, explaining concepts to other students, group writing assignments, case study analysis, writing to a realistic audience, solving (open-ended) what-if problems, and peer review of their work. The benefit of these WAC activities is reflected in the effort to guide the students to more actively participate and be engaged in a full spectrum of Bloom's levels of learning. A comparison of the assignments, the WAC activities utilized in the assignments, and the levels of Bloom's taxonomy which are achieved are summarized in Table 4.

Table 4. A Comparison of Course Assignments, WAC Activities, and Bloom Levels of Learning

Assignment	WAC Activities	Bloom Level°
1) Quizzes	Explaining concepts to other students, brainstorming	1,2
2) Engineering design process	Explaining concepts to other students, brainstorming, group writing assignments, case studies	1,2,3
3) Population projection/water demand	Explaining concepts to other students, case studies, writing to a realistic audience	1,2,3,4
4) Single solution problems	Explaining concepts to other students, brainstorming	1,2,3,4
5) Design statements/summary	Explaining concepts to other students, brainstorming, group writing assignments	1,2,3,4
6) Wastewater treatment exam	Explaining concepts to other students, brainstorming, group writing assignments, solving what-if problems, peer reviews	1,2,3,4,5,6
7) PER of Water Treatment Facility	Explaining concepts to other students, brainstorming, group writing assignments, solving what-if problems, writing to a realistic audience	1,2,3,4,5,6

°1. Knowledge (list, recite, reproduce), 2. Comprehension (explain, paraphrase), 3. Application (calculate, solve, determine, apply), 4. Analysis (classify, predict, model, derive, interpret), 5. Synthesis (propose, create, invent, design, improve), 6.Evaluation (judge, select, critique, justify, optimize)[4].

Conclusions

Factors that have influenced development of the process utilized in the course include the following:

- Writing Across the Curriculum (WAC) training initiated and serves as a base for the approach to this educational process. Faculty and professional staff working in the development of this process have participated in 1-2 WAC training workshops.
- Collaboration between engineering and English faculty and professional staff has strengthened the process through its development.
- Graduate teaching assistants who evaluate work in the course are also trained through the WAC program. Following the WAC training graduate assistants are able to contribute to the course by developing assignments as well as evaluation heuristics.
- Student resistance to course writing requirements has fostered understanding and tweaking of the process.

In addition, the efforts in developing this course and analyzing the outcomes has provided engineering Ph.D. candidates (the graduate teaching assistants for the class) formal training in engineering education along with technical skills development.

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