



Understanding the Expectations of Writing Skills in Engineering Design Courses and Professional Practice

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Understanding student expectations of writing skills in engineering design courses and professional practice

The importance of writing in engineering practice is often not emphasized. As a result, many engineering students do not appreciate the impact of written reports in expressing the engineering content of their design. In this work, writing assignments were incorporated in senior design elective courses of environmental engineering. These courses, *Engineered Environmental Systems - EES* and *Water & Wastewater Engineering – WWE*, focused on concepts related to storm water treatment design and management and water - wastewater engineering principles and design respectively. A variety of writing assignments were given to students in these courses. *WWE* required more design-oriented and technical writing assignments while *EES* required both descriptive and design-oriented writing approaches. The writing assignments in *EES* include a concept report, three engineering design statements and a preliminary engineering design report while *WWE* included free writing, exploratory writing, formal writing, informal writing and reflective writing exercises. This paper will present the trends in student learning curves across two semesters. The evaluation criteria was based on the components such as consideration of audience (15%), quality of solution (15%), rigor of engineering analysis (25%), organization and focus (15%), clarity and coherence (15%), and professional appearance (15%). A comparison of student performance in terms of content accuracy, language issues and effect of writing expression between the three courses will be presented. The relationship between the number of errors and the type of writing activity was evaluated for the three semesters. The major differences in student performances among the different course writing assignments were characterized as “misconceptions of effective writing”, “weak language skills” and “ignorance of professional practice expectations”. The student experiences were also gathered through a survey consisting of questions related to their learning process and the expected engineering course outcomes. Lessons learnt from these engineering design and writing assignments and future direction will be discussed in this paper.

Introduction

The engineer training can be facilitated by integration of communication skills, especially in written form to reflect actual practice in the professional environment^{1, 2}. Writing should be considered as a core activity of the engineering design and project development and inseparable from other tasks. In some instances, technical communication courses fall behind accomplishing this objective because these courses are not necessarily constructed to incorporate engineering design and communication of the design elements in written justification that would make the overall engineering design process a meaningful task rather than just number-crunching and design-drawing activity³.

Conventional approaches to teach design skills, such as working numerical problems, routine programming are not adequate to help students learn the soft skills, i.e., process skills required to develop a comprehensive solution to an engineering problem⁴. Although the conventional approach is still important, lifelong and project-oriented learning for engineers is considered a fundamental education in recent times⁵⁻⁷. Providing engineer training to meet this goal is quite challenging. The degree to which the students develop skills depends on how they solve problems, write reports, function in teams, self-assess and do peer-review, learn new knowledge and adapt to changing professional expectations⁸⁻¹¹. Recent research shows that engineer training and development of critical design skills can be facilitated by providing practice through several mechanisms that would allow for critical thinking. Instructors should not only simply demonstrate the problem solving, but also coach students to develop similar skills and higher levels of learning⁸. A number of approaches are available to achieve this objective, by project based learning, and thinking aloud pairs problem solving, among others. Writing assignments combined with design exercises are also ideal for allowing students develop these skills efficiently with practice.

Writing can be introduced in number of stages in any engineering design course^{1, 12-14}. First, by requiring periodic goal statements and subsequent progress reports rather than the final technical merit. This would allow for students to make slow and steady progress toward an ultimate goal and being held accountable for setting, achieving, and reporting appropriate intermediate goals. Followed by this activity, students should be given opportunities to justify their design in both written and oral forms. Defense of engineering design in oral form would provide opportunity for the students to prepare for realistic environment of a work place. Finally, encouraging students to refer to engineering journals and other accessible resources relevant to engineering practice would promote an awareness of the language and logic of technical articles and lead students to adopt these standards in their own writing¹¹.

We have incorporated various types of writing exercises to enrich the engineering design experiences in our senior environmental engineering design elective courses *EES* and *WWE*. *EES* included informal writing, free writing, exploratory writing, formal writing (project report), and reflective writing while *WWE* included conceptual design report, design statements and a preliminary design report. These writing assignments were designed to achieve the following objectives¹⁵:

- To help students recognize the importance of writing in the classroom and in professional engineering practice.

- To use writing as a way for students to learn and clarify thinking.
- To establish sufficient opportunities to practice and develop their professional writing skills.
- To use writing as a mechanism to defend and justify the engineering design.

Writing assignments were used to create a practical context that deepens their understanding and comprehension of the content area¹². The sequence of assignments designed in this study progressively advances students from solving single solution problems to more complex open-ended problems that more closely resemble the engineering design process. The following sections will describe the writing exercises given to reinforce the course material in engineering design projects. A comparison of student responses on the basis of expected outcomes is provided to understand the effectiveness of each writing exercise. Students responses were evaluated using both number scale (1-5, 1 being low impact and 5 being high impact) and ratings (SD – strongly disagree; D – Disagree; NA/ND – neither agree nor disagree; A – agree; and SA – strongly agree). The comparison includes four components through which the intangible benefits of writing activity can be assessed. These include: thinking patterns (critical, creative, and reflective thinking), course related objectives (learning experiences, opportunities for deeper understanding, and realization of writing as a mechanism), accomplishing intangible ABET outcomes (outcomes f through j), and higher levels of student learning on Blooms taxonomy.

Description of writing assignments

An outline of writing assignments given to students in *Engineered Environmental Systems, EES* and *Water & Wastewater Engineering, WWE* is given below while complete descriptions are provided in Table 1 and Table 2 respectively.

Engineered Environmental Systems, EES

To enhance student learning of the subject matter, several writing exercises were included. Informal writing involved a critical review of different stormwater pollution management issues and current best management practices and a comparison of the alternatives. Free writing was given in class to promote free thinking and thinking through writing. Exploratory writing exercise involved a topical discussion of stormwater treatment process. A formal writing exercise was given in the form of a stormwater pollution prevention plan (SWPPP) assignment which included a peer-review session prior to final grading. A reflective writing exercise was included to summarize learning experiences through classroom and writing activities throughout the semester to identify areas of strengths and weaknesses and accomplishments and pitfalls and areas/topics for future development.

Table 1. Description of writing assignments in *EES*

Name	Description
<i>Free writing</i>	Students were asked to write freely without a concern for sentence structure, grammar, logic and continuity, and scientific merit or technical correctness of the topic. Students were given 10 minutes to think and write on a topic of their interest within the course content. This is a classroom exercise.

<i>Exploratory writing</i>	Students were asked to prepare a short essay of 500-1000 words on a topic of their interest within the course content related to stormwater management and treatment alternatives.
<i>Informal writing</i>	A critical review of the existing storm water management practices and alternative design practices for facilities in any one of the standard industrial sectors (up to 1000-1500 words).
<i>SWPPP Report (Formal Writing)</i>	A technical report encompassing the storm water pollution prevention plan for a given site and a justification essay for the design or selection of the best management practices. This exercise included a peer-review and a revision stage prior to submitting the final draft.
<i>Reflective writing</i>	An exercise to reflect on one's own learning process through writing exercises to acknowledge strengths and weaknesses and areas for improvement (500-1000 words). This exercise included a peer-review and a revision stage prior to submitting the final draft.

Water & Wastewater Engineering, WWE

The final goal of the course is to produce a preliminary engineering design report. First, the students were asked to develop a conceptual design report which includes the evaluation of background information and historical population and water use data for a given city followed by an analysis of future water supply needs in view of future population and economic development of the city and identification of an appropriate water treatment technique and design. This task is followed by design statements for individual unit operations and processes identified in conceptual design report. The final assignment is to design the 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.

Table 2. Description of writing assignments in *WWE*

Name	Description
<i>Conceptual Design Report</i>	This report addresses the factors requiring consideration in the design of a new water treatment plant for a given city. Factors influencing water demand are discussed as is the best site for a new water treatment plant. Water sources and water quality information is also provided. Existing water treatment and possible other treatment options are discussed as is the need for a new water treatment plant.
<i>Design statements (1-4)</i>	These include Goals (2-3 sentences), Objectives (2-3 sentences) and information related to flow, concentration and other water quality information, treatment scheme (small diagram/flow chart) and highlight the process for the design Statement, list of design parameters, design range for parameters with references and selected ranges, justifications for selection of design ranges, less than two pages in length. There is no limit for appendix material. The design statement can be provided in narrative form or in tabular form and any other appropriate forms.
<i>Preliminary Engineering Design Report</i>	The report 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 safe drinking water act (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.

Evaluation Criteria

An evaluation heuristic is used to grade the reports which is also provided to the students. Evaluation criteria include the following components¹²: 1) Consideration of audience - specifying the client and clearly addressing all the client's needs (15%), 2) Quality of solution - clear description of the problem and evaluation of the proposed solution with a persuasive argument (15%), 3) Rigor of engineering analysis - relevant data, background and research pertinent to the problem, methods, calculations, analysis, and conclusions based on evidence (25%), 4) Organization and focus - effectively organized, engaging and easily followed (15%), 5) Clarity and coherence - flow in thought, transitions, graphical presentations, grammar/mechanics (15%), and 6) Professional appearance - a consistent professional format (15%). The first three components address the technical/engineering content and the remaining components address effective communication and professional appearance.

Results and discussion

An example of the instructor's objectives for the writing assignments/exercises are summarized in Figure 1. Instructor's objectives for writing assignments were:

1. To help students recognize the importance of writing for the course and profession.
2. To promote a desire to correct their writing deficiencies and to improve professional writing skills.
3. To use writing as a tool to learn and clarify thinking and promote critical thinking.
4. To establish sufficient opportunities to practice and develop writing skills.
5. To give appropriate advice, criticism, and correction to promote improvement through revision.

As shown in Figure 1, some of the exercises were given points for participation while the others were graded using the evaluation criteria including feedback from peer-review and revision progress. The scores were affected by the quality of presentation (including grammar, expression and style) and the rigor of engineering thought process and design as evidenced by the depth of discussions provided in the writing exercises. Overall, the quality of writing has improved with continued writing activity through different exercises. As an example, exploratory writing was the first of the three writing intensive exercises in *EES* course. The average score for this exercise was lower than other exercises as shown in Figure 1. Students performed better in subsequent exercises with continued feedback. The student learning experience is also reflected through their responses as discussed in later sections.

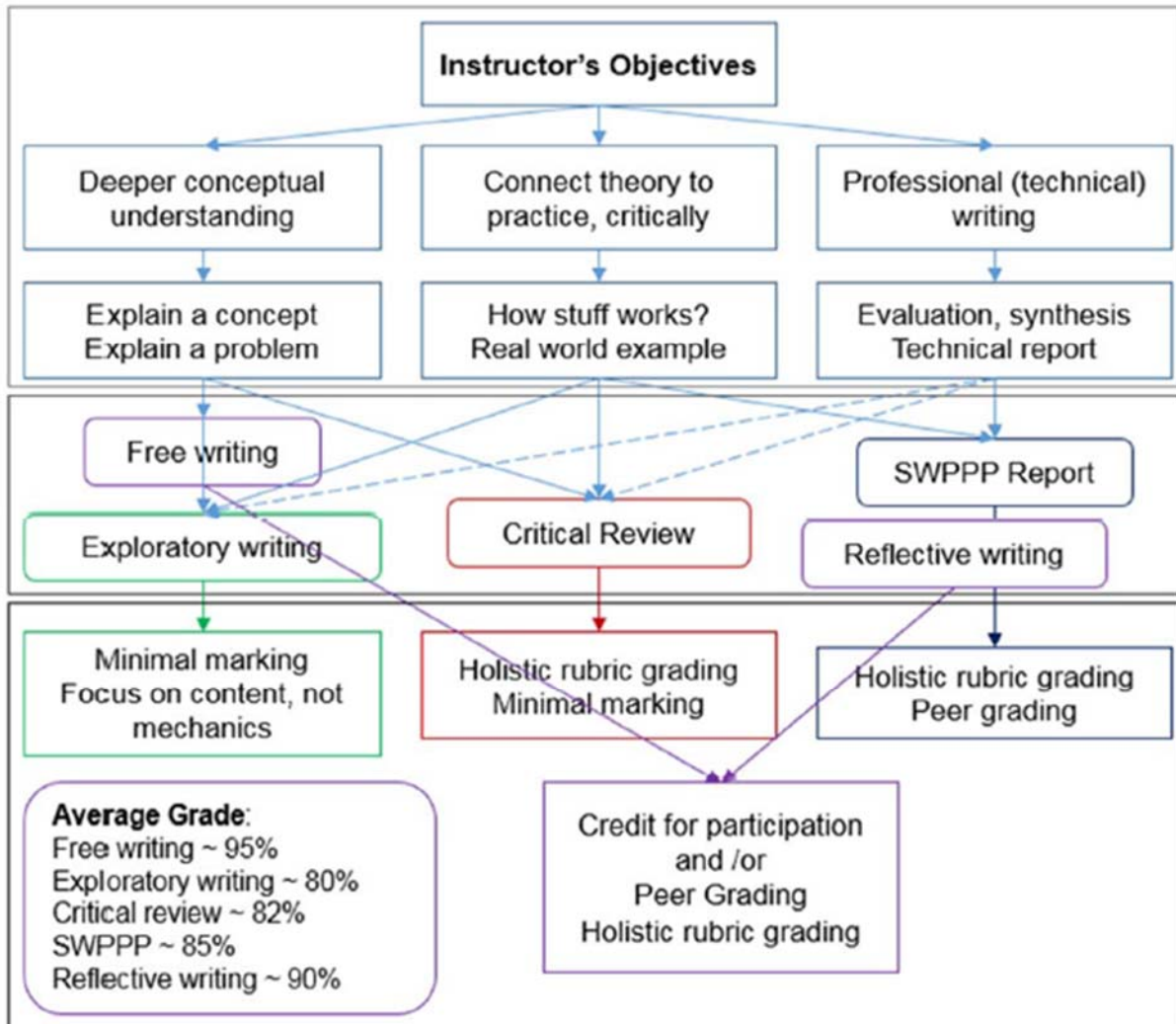


Figure 1. Instructor's objectives, connection to assignments and grading methods for *EES* Course

Writing assignments also provide opportunities for exercising critical thinking, creating thinking, and reflective thinking essential for an effective engineering design. The average responses varied between 3.4 and 4.2. The average student responses were consistently lower for *WWE* when compared with *EES* for all types of thinking.

Students' responses on the ability of writing assignments to provide opportunities for developing critical thinking, creative thinking and reflective thinking (Figure 2) all followed a similar pattern in that 52%-61% of the students agreed that the writing assignments were helpful to develop these skills in *EES* while 36%-40% students agreed that writing assignments helped develop these skills for *WWE*. 6%-18% of the students in *EES* and 26%-33% of the students for *WWE* neither agreed nor disagreed while 16%-30% of the students strongly agreed to this effect in both courses.

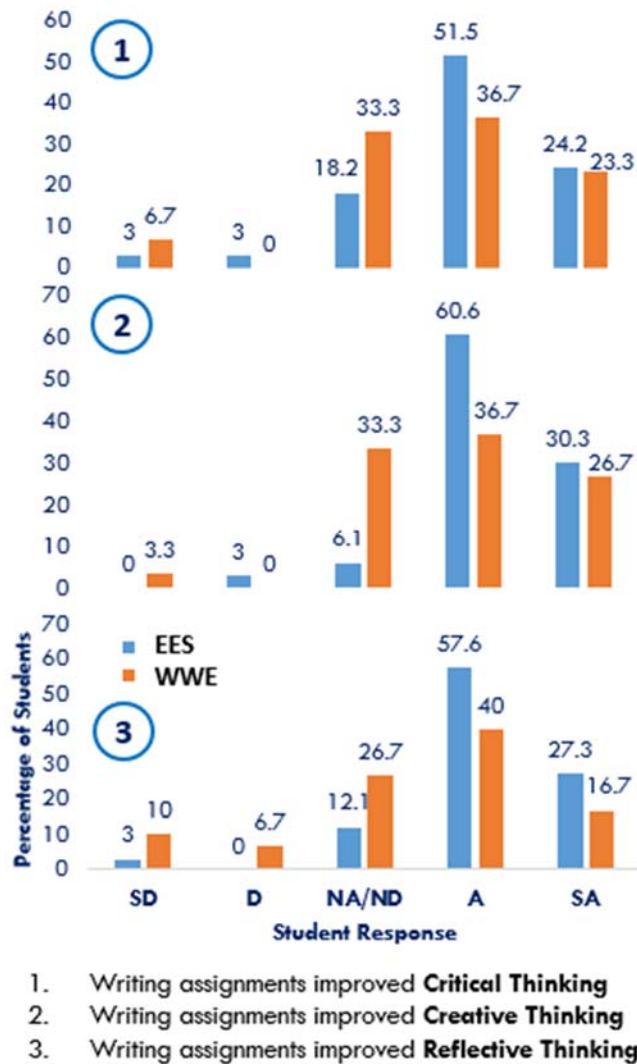


Figure 2. Student responses to effectiveness of writing exercises in promoting critical, creative and reflective thinking skills

A set of questions were focused on appropriateness of writing exercises and the opportunities provided through them. Responses to these questions are shown in Figure 3. Consistently higher ratings were noted in *EES* for all questions. The appropriate number of writing assignments were 3.3 and 2.4 for *EES* and *WWE* respectively. The difference between the two average ratings could be due to the repetition of design statements for different unit operations in *WWE* which is the design of water treatment system unit operations.

Some general questions about the writing assignments in relation to the course content were asked. The results are as follows.

- 72% and 60% of the students agreed or strongly agreed that these assignments improved their learning experience in *EES* and *WWE* respectively
- 85% and 50% of the students agreed or strongly agreed that these assignments instilled interest in the subject matter in *EES* and *WWE* respectively

- 61% and 60% of the students agreed or strongly agreed that total number of assignments (five) was adequate
- 75% and 70% of the students agreed or strongly agreed that these assignments were appropriate for the course
- 88% and 57% of the students opined that three to five writing assignments would be appropriate for the course.

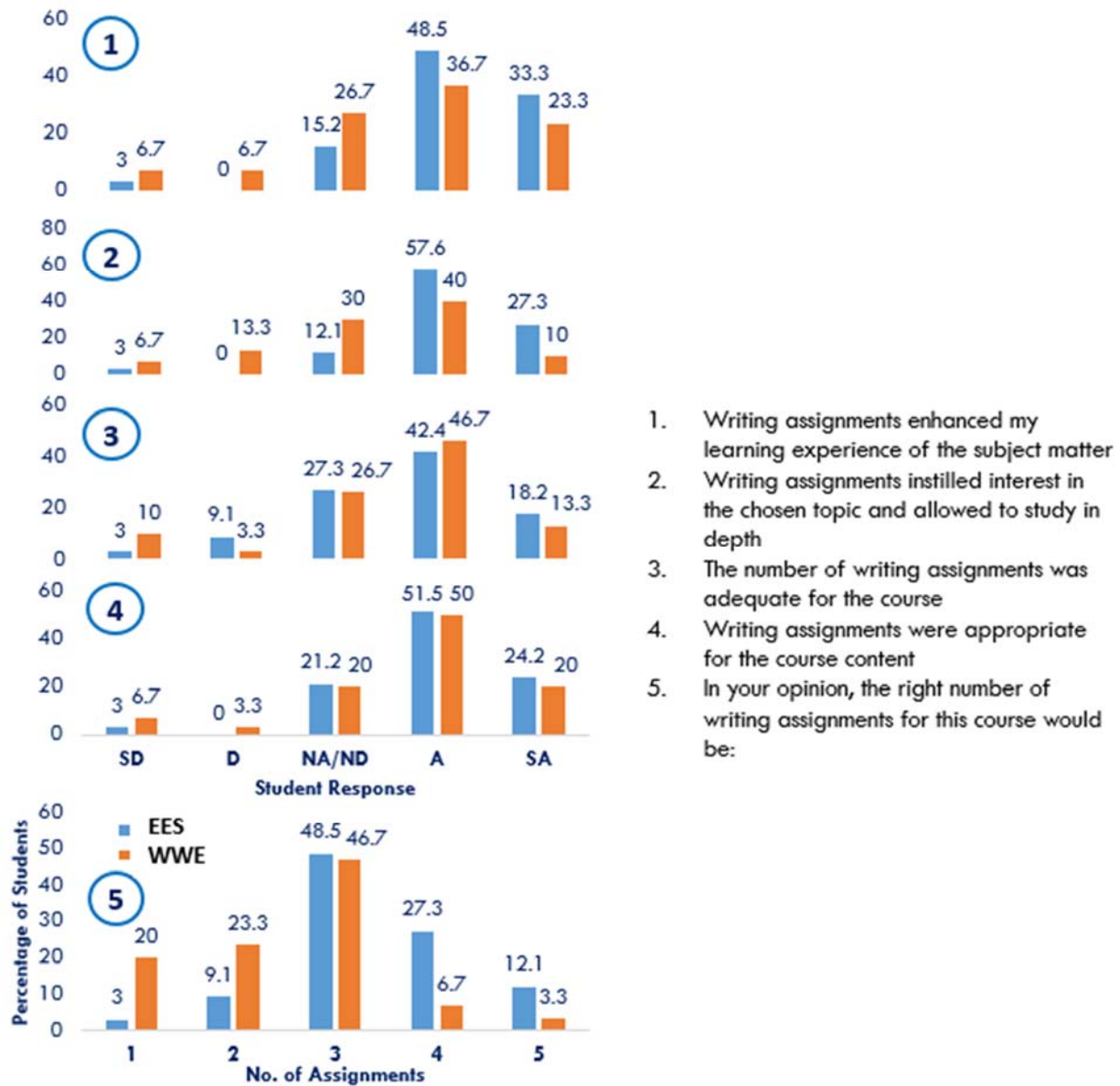


Figure 3. Student responses to appropriateness of writing exercises in two environmental engineering design elective courses.

From the responses in Figures 2 and 3, it can be noted that up to 30% of students have expressed a neutral opinion on the effectiveness writing exercises. It may be because, in general, engineering programs and courses do not emphasize on writing assignments as a way of promoting deeper learning of the course content. The students (as well as many instructors) carry a perspective that engineers do not need to write and therefore they do not need good writing skills. Other than English composition and technical writing courses offered in freshmen to sophomore/junior levels in the curriculum, most of the other engineering courses do not incorporate writing exercises. Therefore students may find themselves out of place when they have to work on a writing exercise that is not “typical” of a subject-oriented engineering design elective course. This should be considered a critical outcome. The instructor has strived to help students realize the importance of writing by providing examples from his own professional experience and others. Students were reminded in a number of occasions that they are nearing graduation and need skills such as these to communicate effectively with their clients and employers.

Writing exercises provide a mechanism for achieving ABET^{16, 17} stipulated engineering education outcomes under criterion 3 (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) which are hard to achieve in a traditional compartmentalized engineering curriculum. These intangible ABET outcomes can be better accomplished through writing assignments to engineering students. Figure 4 shows the responses to the effectiveness of writing exercises in accomplishing ABET outcomes f through k.

Slightly higher ratings were received for *WWE* for outcomes f, h and i. Similarly, outcomes g, j and k received slightly higher ratings for *EES*. Again, these observations are as anticipated given the nature of the writing exercises incorporated in each of the courses. Writing intensive exercises in *EES* enhanced the communication skills, knowledge of contemporary issues and techniques and skills required for engineering practice¹¹. The design intensive exercises in *WWE* helped students realize the professional and ethical responsibility, awareness of broad education for engineering solutions, and the need for life-long learning to stay up to the trends in engineering practice¹⁸.

Summary of students’ responses on intangible ABET outcomes (f) through (j) are shown in Figure 4.

- 61% and 70% of the students agreed or strongly agreed that writing assignments have developed an understanding of professional and ethical responsibility in *EES* and *WWE* respectively
- 65% and 53% of the students agreed or strongly agreed that writing assignments have improved the ability to communicate effectively in *EES* and *WWE* respectively
- 69% and 80% of the students agreed or strongly agreed that writing assignments have increased the awareness of the broad education necessary to understand the impact of engineering solutions in a global, economic, environmental, and societal context in *EES* and *WWE* respectively

- 63% and 63% of the students agreed or strongly agreed that writing assignments have developed an understanding of need for life-long learning in *EES* and *WWE* respectively

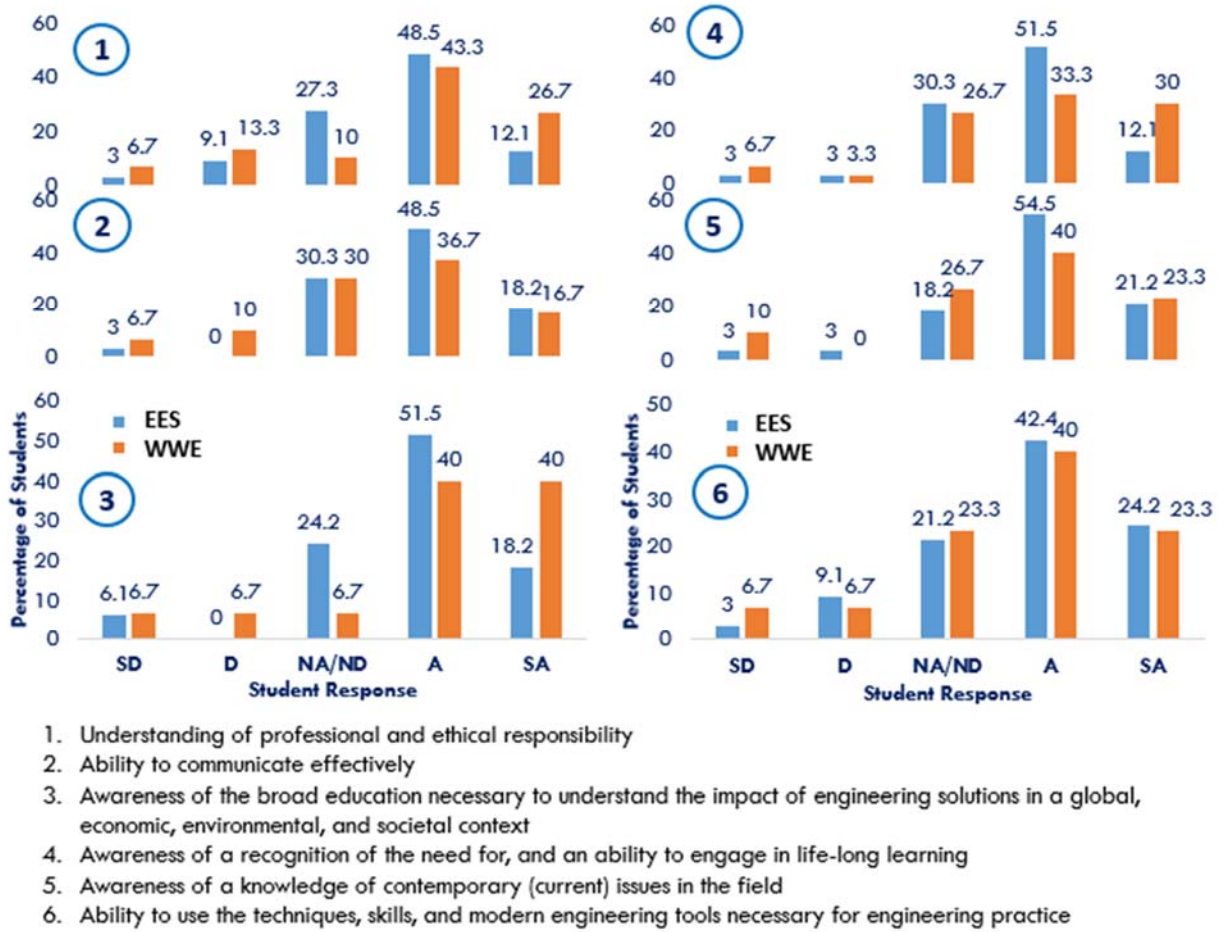


Figure 4. Student responses to the effectiveness of writing exercises in accomplishing ABET outcomes f through k.

Comparison of student responses in Courses A and B

A comparison between the levels of learning (Bloom’s Taxonomy^{19,20}) reported by students for *EES* and *WWE* reveals that ‘synthesis’ and ‘evaluation’ were the highly exercised skills for *WWE* while “knowledge”, “application” and “evaluation” were the highly exercised skills for *EES* (see Figure 5). These results are somewhat anticipated considering the nature of the writing exercises given to the students in respective courses. In *EES*, the writing assignments were focused on the stormwater design and management plan which were not design-intensive. In *WWE*, the students were required to gather information through research followed by a critical evaluation and proposal and comprehensive design of individual unit operations which was proved to be challenging to the students. The students were not given a lot information on design specifics or

details rather they were allowed to explore various options in order to arrive at a conclusion. Moreover, each student team worked on a unique municipality in the state of Mississippi although a few teams designed water treatment systems for cities in other states.

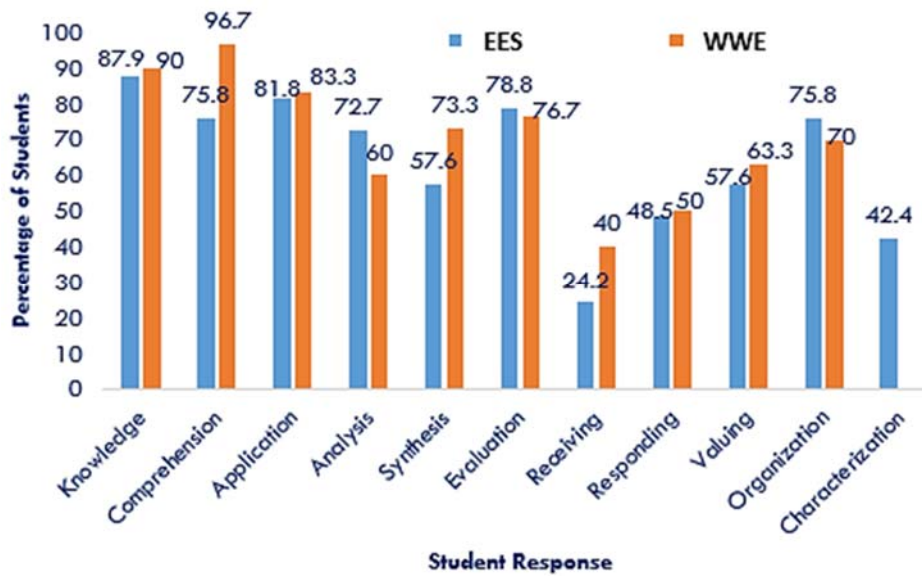


Figure 5. Student responses to five levels of learning in both cognitive and affective domains of Bloom's Taxonomy of learning levels.

Conclusions

Student learning experiences and the effectiveness of different writing exercises in two senior environmental engineering design elective courses were discussed. A comparison of the perceived benefits of writing exercises through the ABET outcomes and Blooms learning levels was presented. The survey responses and evaluation of students' performance show that writing assignments played an important role on how students learnt and which benefits they perceived most. This study indicates that a mix of well-balanced writing and design oriented exercise with an appropriate level of written guidelines and expectations for the writing exercises could help students experience the engineering design process similar to professional engineers.

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