Teaching Non-Engineers the Engineering Thought Process with Environmental Engineering as the Instrument

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Abstract

Environmental engineering is a broad discipline with seven areas of specialty as identified by the American Academy of Environmental Engineers. Based on application of the environmental engineering program criteria, an ABET accredited program's curriculum requires students to have familiarity with each of these specialty areas. The challenge in an undergraduate program is to provide this breadth of material coverage while simultaneously presenting courses in a logical fashion so that they build upon and reinforce one another and not appear as individual, disjointed topics. Aligning courses and their content with the engineering thought process is one approach that can achieve both objectives. This paper describes how this concept is applied to a three course engineering sequence offered as a part of a core curriculum to non-engineering students at the United States Military Academy. Engineering design steps such as problem definition, design and analysis are linked with fundamental environmental engineering concepts like risk assessment, pollutant partitioning, and materials balance. Examples of how course objectives, laboratory exercises, and course projects are associated across the program using this framework are provided. By presenting environmental engineering topics oriented along a common theme that is known by the student and reinforced throughout the program of study, these students will be better equipped to solve complex, environmentally related problems and better prepared for specialization in future graduate studies.

Introduction

Founded in 1802, the United States Military Academy (West Point) was the nation's first engineering school. Over the years as missions and requirements changed West Point broadened its academic diversity and is no longer strictly an engineering school and today offers majors in 31 different academic disciplines that culminate in a Bachelor of Science degree. The division between cadets majoring in Math, Science, and Engineering (MSE) and Humanities and Social Sciences (HPA) has been relatively even (Figure 1). Regardless of major, every cadet's core curriculum includes an MSE thread. Courses in this thread are intended to "provide cadets a foundation of fundamental scientific facts and principles, an understanding of the engineering process by which these principles are applied to serve human purposes, and the capacity to use sound methods for analyzing and dealing with scientific and technical matters."[1] This MSE thread is in part fulfilled by a three course engineering sequence. West Point offers seven different engineering sequences from which non-engineering majors can select. The seven engineering sequence are in civil, computer science, electrical, environmental, mechanical, nuclear, and systems engineering. As depicted in Figure 1, the number of cadets enrolled in an engineering sequence is increasing.

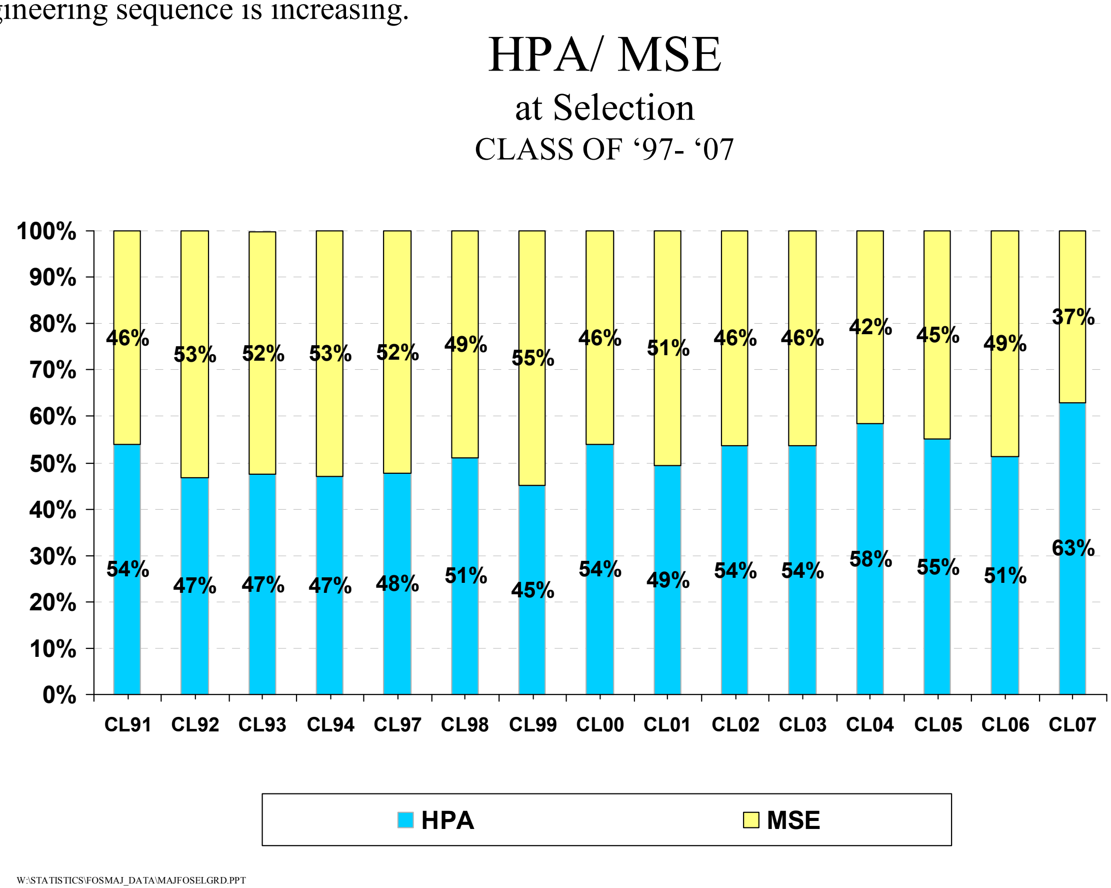

Figure 1. Declared Majors -- Humanities and Social Sciences (HPA) and Math, Science and Engineering (MSE). [2]

This paper describes how the environmental engineering sequence aligned its courses and content with steps in the engineering design process. Engineering design steps such as problem definition, design and analysis were linked with fundamental environmental engineering concepts like risk assessment, pollutant partitioning, and materials balance. Examples of how course objectives, laboratory exercises, and course projects fit in to this framework are provided. By presenting environmental engineering topics oriented along a common theme that is reinforced throughout the program of study, students in the sequence will better understand how to solve complex, engineering oriented problems in real world scenarios in the Army.

The Engineering Design Process

Seventy-two percent of the West Point Class of 2007 is enrolled in one of the three-course core engineering sequences (Figure 2). In a trend common to the nation,[3] West Point has seen a decrease in the overall number of engineering majors. Participation in an engineering sequence provides cadets exposure to the engineering discipline and has the potential of influencing future increases in an engineering major. Excellence in engineering education with these non-engineers therefore holds a dual importance for the engineering profession as a whole;

an appreciation for what engineers do and advertisement to reinvigorate interest in the engineering profession. The initial obstacle is convincing cadets that the engineering sequence reinforces studies in their chosen major. [4]

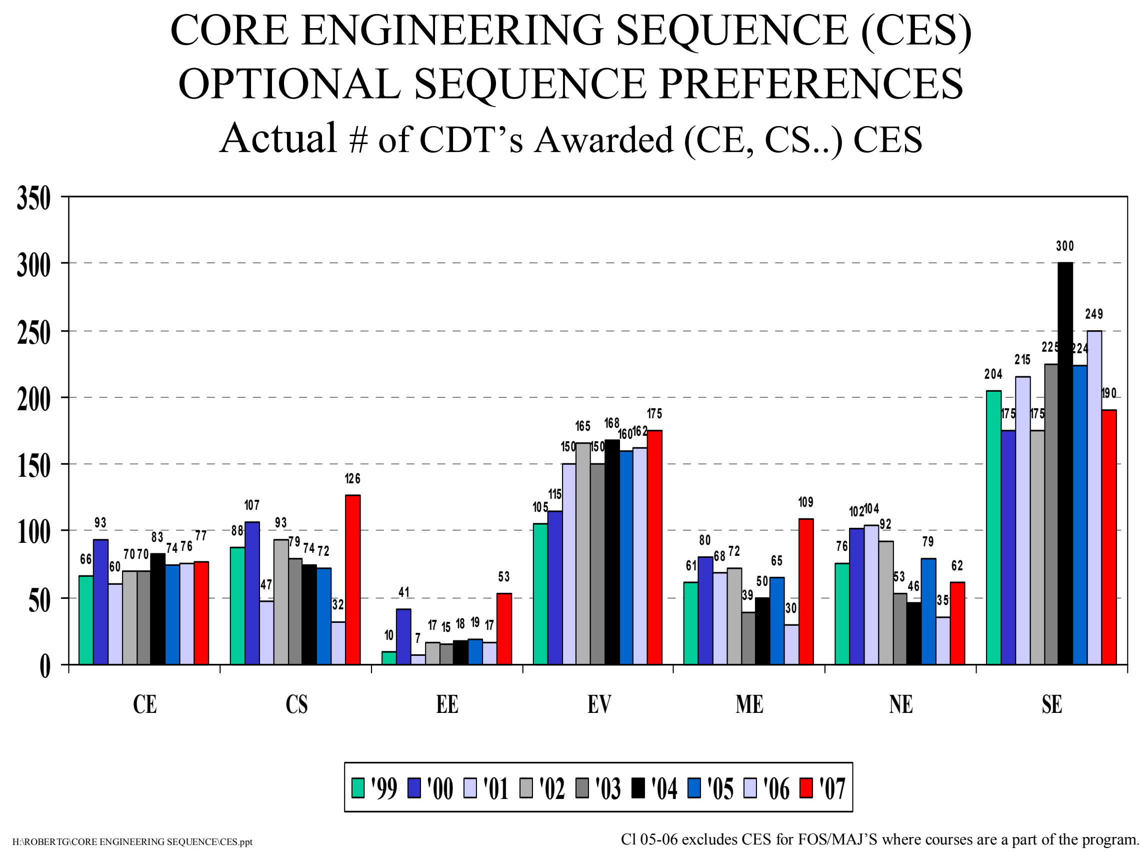

Figure 2. Enrollment History by Engineering Sequence (sequence in graph matches legend) [5]

To provide strategic guidance for the Academic Program, the Academy published Educating Future Army Officers for a Changing World. Stated in this document is the overarching goal of the Academic Program; "to enable graduates to anticipate and respond effectively to the uncertainties of a changing technological, social, political, and economic world." Ten specific program goals are used as indices of attainment of the overarching goal. Proficiency in the Engineering and Technology (E&T) domain of knowledge is one of these specific program goals. To "ensure that cadets studying engineering in different disciplinary domains have a common basis for their engineering design experience and a common mental model of the process," each engineering sequence will apply the engineering design process (Figure 3). Communicating the engineering design process is a common thread in engineering sequence courses. [6] The environmental engineering sequence went beyond teaching the engineering design process and opted to align each of the three courses with one of the major steps in the process. Doing so provided a natural flow and connectivity among the courses.

The first course in the sequence, *Environmental Science* (EV300), is aligned with the *Problem Definition* step. The course focuses on using science to define the reason behind and degree of importance of environmental problems environmental engineers are asked to solve.

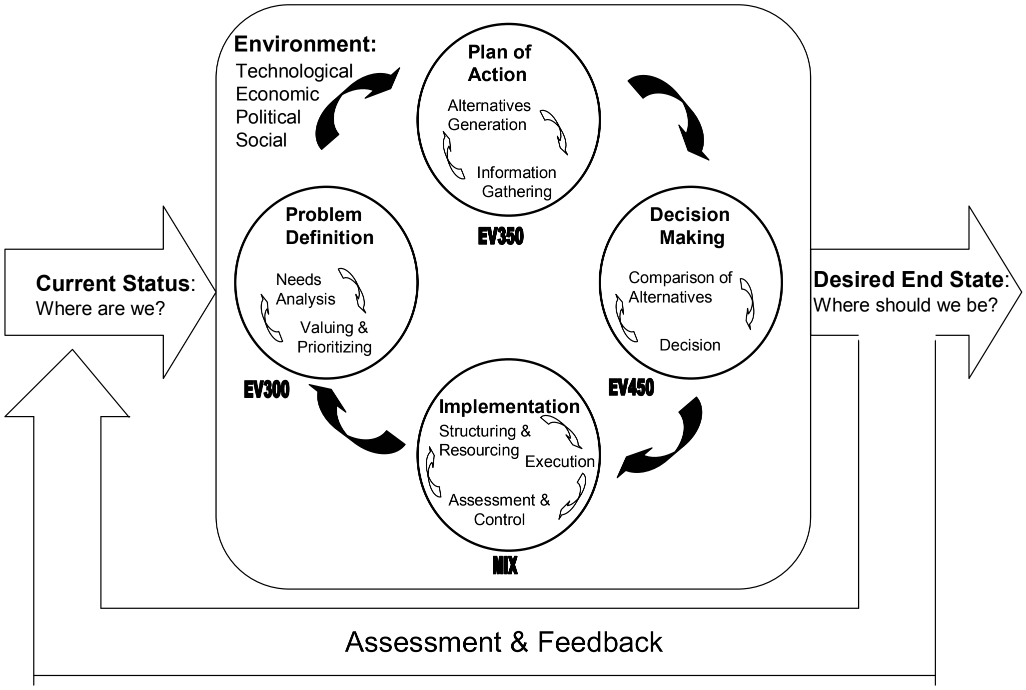

Figure 3. Phases of the Engineering Sequence Design Process.

Coverage of basic engineering science principles is a common theme in understanding issues and why they exist. [7] *Environmental Technologies* (EV350), the second course in the sequence, is aligned with the *Plan of Action* step. It is in this course that engineering design is taught as solution alternatives to environmental problems. Engineering design provides alternatives to solve water, air, and solid waste pollution. *Environmental Decision-Making* (EV450), the final course in the sequence, is aligned with the *Decision Making* step. In this course emphasis is not only placed on providing cadets with a decision making tool but also on how to incorporate economic, social, and political considerations in their comparison of alternatives.

EV300/301, Environmental Science (Problem Definition)

This course is structured to introduce cadets to how human use of technology and manipulation of the natural environment results in environmental problems. Cadets see that fundamental physical, chemical, and biological principles in nature allow us to predict pollution impacts on an ecosystem. Ethics, risk analysis, and statutes are introduced to help cadets prioritize the importance of environmental issues. Cadets engage in point, counterpoint debates to sharpen their problem recognition and valuation of presented information. The scientific method-based course project is used as a variant of the engineering design process to teach cadets how to identify a problem, establish a testing protocol, and draw conclusions. Labs focus on testing a hypothesis. Guest lecturers provide external perspectives of issues discussed in class like global warming. Field trips to places like a recycling facility explores waste minimization.

EV350, Environmental Technologies (Plan of Action)

Cadets practice solving environmental problems via the control of physical, chemical, and biological processes to achieve a desired outcome. How a contaminant partitions helps cadets determine where focusing their engineering efforts will pay the greatest dividends. The selection of a particular unit process over another is in part based on information gathering such as characteristics of what the contaminant, process requirements, and characteristics of the process's outputs. A block on hazardous waste integrates concepts taught during the course to be systematically applied to remediate an environmental issue spanning the water, the air, and biota. Labs focus on applying scientific principles to the solution of environmental problems. Field trips are to observe treatment trains at the local drinking water and wastewater treatment plants. The design problem allows cadets to explore the consequences of discharge on an aquatic environment and then design alternative solutions in a deployment based scenario.

EV450, Environmental Decision-Making (Decision Making)

This course completes the sequence and teaches cadets how to integrate engineered solutions with social, political, and environmental considerations and effectively communicate and defend a recommendation to both technical and non technical audiences. The emphasis of the course is on decision making techniques and their application to include using a decision matrix to formulate criteria (to include environmental impact), mature alternatives, compare these alternatives, and recommend a solution for implementation. Evaluation includes engineering feasibility economics, and trade off analysis. Cadets explore case studies as examples of decision making and conduct an independent research project concluded with an oral presentation of their decision making process and recommendation. Guest lecturers share real world experiences examples of project management successes and failures.

Elements Common to All Courses in the Sequence

Each of the courses share common themes that are oriented at improving the educational experiences of cadets and instructors alike. Many of these teaching methods and assessment mechanisms have been highlighted as applicable to engineering education.[9] First, each of the courses publish for the student course and by lesson learning objectives. These objectives use verbs linked to Bloom's Taxonomy of the Cognitive Domain to guide both instructor lesson preparation as well as cadet assessment preparation. Clear lesson objectives also help cadets understand how lessons, blocks, and courses are linked so that they see the relevance of the material covered. Reading assignments come from both textbook and external sources such as the internet and newspaper articles and limited to about one hour to complete.

Since these cadets are majoring in non-engineering disciplines, effort is made throughout the sequence to show relevance between principles covered in environmental engineering and those in the cadet's own major and their future as leaders in the Army. To supplement classroom instruction, laboratory exercises, guest lecturers, and field trips are interspersed throughout the sequence. Instructors seek to place the responsibility for learning on the cadets by structuring classes to encourage discussion and active student participation in learning. Examples include having cadets solve problems at the blackboard, work in small groups, present current events to the class, and debate points of view and approaches to problems. To support this type of interaction, classroom size is generally limited to no more than 18 cadets (16 in courses with scheduled laboratory sessions) to facilitate cadet/instructor exchange and hands on learning.

Sequence Assessment

The first iteration of the three-course environmental sequence was recently completed by one hundred and fifty-four cadets in the Class of 2005. At the completion of EV450, approximately a third of the cadets were asked to complete an end of sequence survey focused on assessing five internally developed outcomes for the environmental engineering sequence.

1. Describe the role that environmental engineers play in safeguarding society
2. Develop critical thinking skills using the engineering design process to resolve local and global environmental issues
3. Recognize the relevance of math, science, and engineering in defining and solving environmental issues
4. Balance engineered solutions with social, political, and economic concerns to arrive at a feasible and supported decision
5. Be able to clearly communicate difficult concepts such as problem definition, technical descriptions, and risk assessment to an audience with varying backgrounds and opinions

The results to the degree of agreement questions are summarized in Figure 4 below. According to the cadets, the sequence objectives were met and cadets were comfortable in recommending this sequence to others. Future classes will be compared to this baseline assessment.

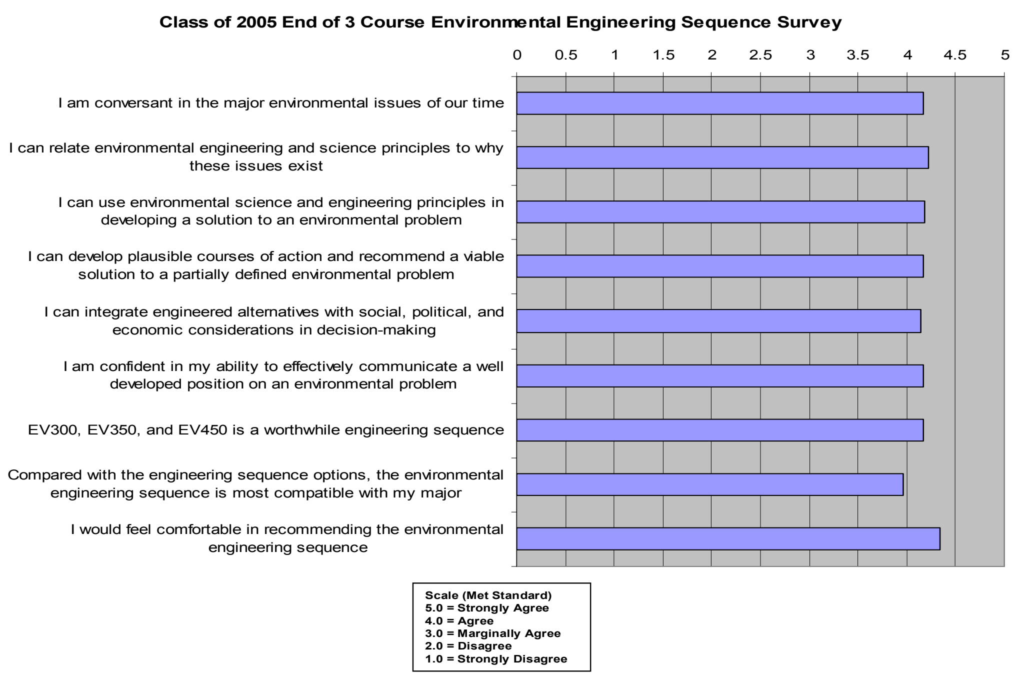

Figure 4. Class of 2005 Sequence Objectives Survey Responses

At the completion of each semester, West Point opens a course feedback system to assess educational objectives and collect input at various levels from the Academy down to the individual instructor. For the environmental programs, a series of questions are included in all end of course surveys to assess the effectiveness of various supplemental teaching/learning methods to include homework, labs, guest lecturers, and the course design project. Summarized in Figure 5 are the results for the Class of 2005 as they responded to this set of questions at the end of each course in the sequence. The weakest area is how cadets perceive guest lecturers throughout the sequence. The reason for the lower opinion of guest lectures is not clear but may be that cadet interaction with the guest lecturer is limited and more exchange would occur if more time could be dedicated to questions and answers than a scripted presentation.

The environmental engineering sequence chose to evaluate success at fulfilling the twelve Engineering and Technology criteria by using cadet performance on the final design projects prepared for EV350 and EV450. The submissions of approximately one third of the population were used in completing this assessment again using a 5.0 scale and the results for the Class of 2005 is summarized in Figure 6. According to the student assessment data the environmental engineering sequence is attaining success in these criteria. Implementation, a design process step that did not have a dedicated course aligned with its coverage was the weakest criteria assessed. Implementation was not well addressed in part because cadets do not actually take any project to this level of completion. The same comment applies to the assessment of the effectiveness of their proposed design. These areas are areas where increased emphasis may be placed in future iterations of the sequence. Having projects sequentially feeding information into the next would allow for better coverage of these two criteria.

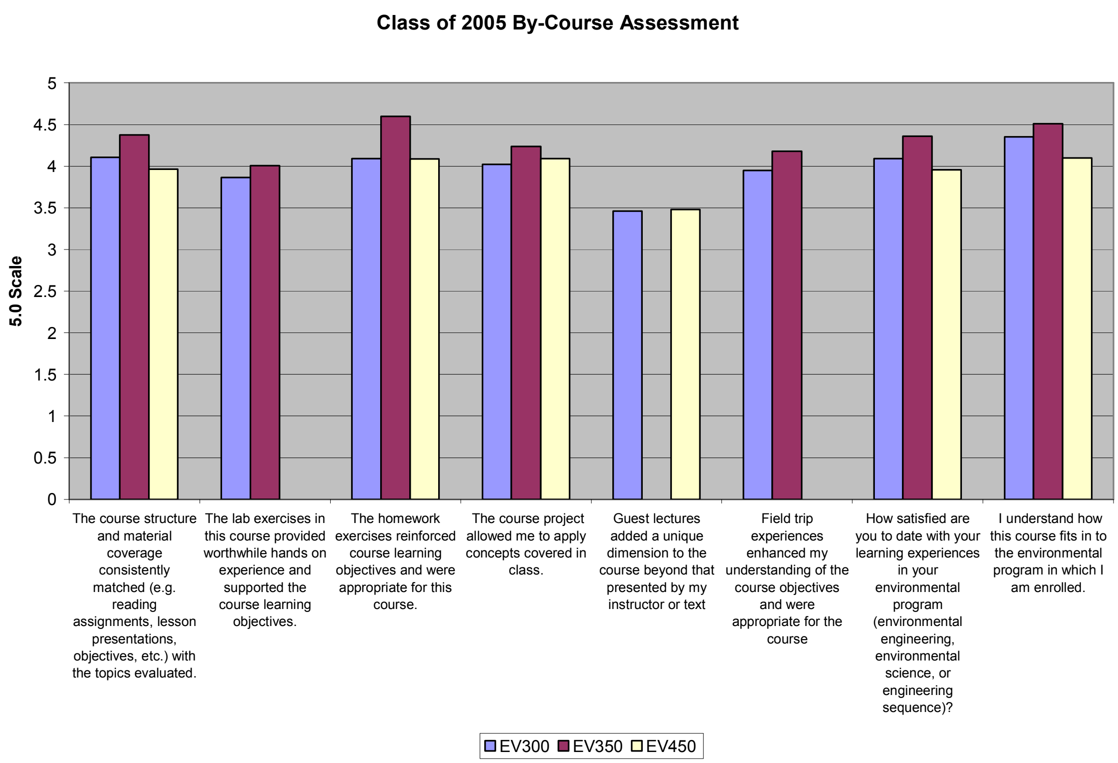

Figure 5. Class of 2005 Responses to Program Level End of Course Survey.

At the end of this current semester, faculty involved in teaching sequence courses did an instructor assessment on how well aligning sequence courses with the engineering thought processes achieved both Academy level and internal expectations. Faculty strongly felt that as individual courses each did an outstanding job in achieving their respective outcomes and both Academy and internal objectives were fulfilled. It was also felt that there was room for improvement in better linking the course threads together so that one train of thought could be carried through the entire engineering thought process. Suggestions included course projects that feed in to each other, using sequence textbooks together in support of each course, and better emphasis on demonstrating to cadets relevance of previous coursework to the present course in the sequence

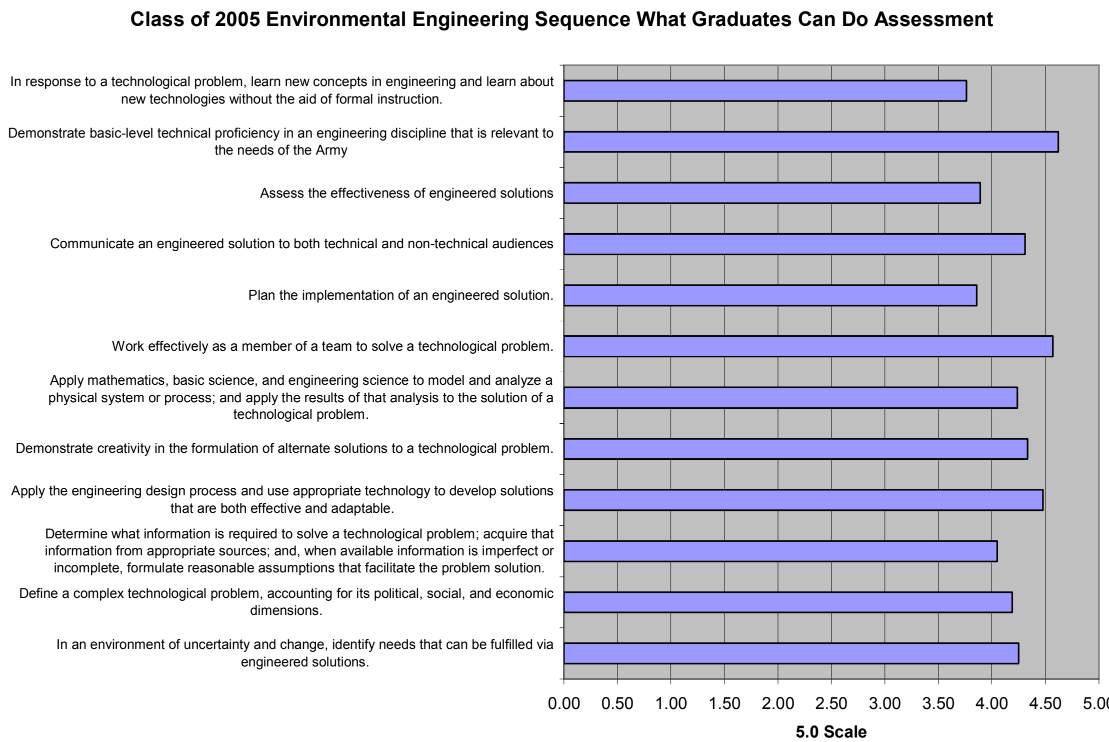

Figure 6. Engineering and Technology Domain What Graduates Can Do Results.

Conclusion

In conclusion, preliminary assessment of a three course environmental engineering sequence taught to non-engineering majors show positive trends. Aligning courses in the sequence with the engineering design process reinforces the engineering and technology goals and adds continuity in material coverage from semester to semester. Results are preliminary with only one set of statistics to base assessment. Assessment mechanisms will be continued so as to provide historical data that will allow better identification of trends and results of planned improvements. One of these improvements is to better integrate the implementation phase of the engineering process.

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