Satisfying ABET's Program Criteria for Environmental Engineering: Experiences with a Laboratory-Based Course in Air Quality

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Abstract

Program criteria for environmental engineering program as stated in ABET's 2015-16 Criteria for Accrediting Engineering Programs requires that the curriculum must prepare graduates to "conduct laboratory experiments and analyze and interpret the resulting data in more than one major environmental engineering focus area e.g., air, water, land, and environmental health." Observation and evaluation of curricula at various accredited environmental engineering programs since 2005 indicates that a majority of the programs achieve this program criteria requirement with water and land as focus areas. This paper discusses the experiences, successes and challenges in teaching a course in air quality which has a significant laboratory component. The course is offered at a small private liberal arts school as part of the curriculum of an accredited environmental engineering undergraduate program. This required-for-graduation course has been taught for over twenty years and along with courses in water quality, soils, hydrology, and water and wastewater treatment, is used to satisfy the 2015-16 program criteria that relates to conducting laboratory experiments in more than one major environmental engineering focus area. Along with the course content and objectives, this paper discusses how the course achieves the Program Criteria and some of the ABET Student Outcomes relating to laboratory experience, and how the results are used in improving the course and the program in general.

Introduction

Accreditation of undergraduate engineering programs by the Engineering Accreditation Commission (EAC) of ABET, Inc. is important for the program, the institution, and its stakeholders including students, faculty members, alumni, and most importantly for employers. An ABET accredited program not only strengthens a student's employment opportunities but also makes the student eligible for licensure and registration in many states for professional practice. In the Commonwealth of Pennsylvania, one of the requirements for certification as an Engineer-in-Training (EIT), the first step towards licensure as a Professional Engineer (PE), is to pass the National Council of Examiners for Engineering and Surveying (NCEES) Fundamentals of Engineering (FE) examination. But one of the ways to qualify to take the FE examination is to graduate from an "undergraduate engineering curriculum in the United States accredited by ABET."[1] As of September 2014, "nearly 3400 engineering programs at nearly 700 colleges and universities in 28 countries" had received accreditation.[2] ABET states that all programs seeking accreditation from the EAC must satisfy the General Criteria requirements at a minimum and an additional set of criteria, *viz.*, the Program Criteria which is determined by the program title.[3] The General Criteria requirement is common for all engineering programs and consists of eight criteria that must be satisfied. The eight criteria are Students, Program Educational Objectives, Student Outcomes, Continuous Improvement, Curriculum, Faculty, Facilities, and Institutional Support. Program Criteria on the other hand are discipline specific and are provided by the lead society in the discipline. The lead society for environmental engineering is the American Academy of Environmental Engineers and Scientists (AAEES) with contributions from several other professional societies including the American Society of Civil Engineers (ASCE), and the American Society of Mechanical Engineers (ASME), among others. As of summer 2015, there were nearly 70 ABET accredited undergraduate programs in environmental engineering in the United States. The name of the program varies but most of accredited programs are named "Environmental Engineering" and have adopted program criteria for environmental engineering.

Studies focusing on assessment of General Criteria in civil and environmental engineering programs indicate that not all educational attributes are considered to have equal significance by various program stakeholders.[4] AAEES Program Criteria for "environmental and similarly named engineering programs" states, among others, that the program must prepare graduates to be "proficient in conducting laboratory experiments and critically analyzing and interpreting data in more than one major environmental engineering focus area, e.g., air, water, land, environmental health."[5] Other curricular requirements that the programs must prepare graduates to be proficient are: mathematics through differential equations, probability and statistics, calculus-based physics, general chemistry; an earth science (e.g., geology, meteorology, soil science); a biological science (e.g., microbiology, aquatic biology, toxicology); fluid mechanics; introductory level knowledge of environmental issues (air, land, and water systems and their associated environmental health impacts); performing engineering design; advanced principles and practice relevant to the program objectives; and understanding of concepts of professional practice.

With the field of environmental engineering evolving at a rapid pace, programs have a variety of topics to choose from to satisfy accreditation requirements. With respect to the program criteria relating to proficiency in conducting laboratory experiments and critically analyzing and interpreting data in more than one focus area of environmental engineering, personal observation and evaluation of curricula at various accredited environmental engineering programs since 2005 indicates that a majority of the programs achieve this program criteria requirement with water and land as focus areas. This paper discusses the experiences teaching an air quality course which has a significant laboratory component for over 20 years, its successes, and challenges in meeting the accreditation program criteria requirements for environmental engineering programs.

Program Curriculum

The BS in Environmental Engineering (ENV) program is one the three accredited engineering programs offered at the author's home institution and has been accredited since 1996. The private institution has historically been known for liberal education with a major emphasis on undergraduate teaching and research. The current program's curriculum supports the program educational objectives that include preparation for practice in key areas of environmental engineering, preparation for professional registration, and acceptance to a graduate program, among others. A minimum number of 134 credits have been required for graduation for the past twenty years. These consist of 25 credits in general education, 24 credits in physics, chemistry, and mathematics, 52 credits in required environmental engineering and environmental science courses, 12 credits of technical electives, and 3 credits as free electives. At least 54 credits (*i.e.*, 40%**)** of the ENV program curriculum are dedicated to engineering topics and include courses in engineering sciences and engineering design. In addition, all students in the major are required to take the Fundamentals of Engineering examination before graduation. Other university-wide graduation requirements include two courses each that are designated as “writing intensive (WI)”, “oral presentation option (OPO)”, and “computer intensive (CI)”. In the ENV program curriculum, the two senior capstone project courses satisfy the WI and OPO requirements; Hydrology and Air Quality are the two courses that are designated as CI and satisfy the graduation requirements.

Engineering topics that are part of the curriculum are appropriate to the discipline of environmental engineering in many ways. Courses like CADD Laboratory, Engineering Project Analysis, and Professionalism & Ethics, Statics, Strength of Materials, Engineering Thermodynamics and Fluid Mechanics support material and concepts in courses such as Environmental Engineering Hydraulics, Water Quality, Water and Wastewater Treatment, Air Quality, and Air Pollution Control. Moreover, topics covered in the above mentioned courses constitute basic engineering fundamentals that are covered in the F.E. examination and in the general practice of any of the engineering specialties. They also provide the basis for future professional development as they serve as prerequisites to advanced environmental engineering courses. The culminating capstone design project course is spread over the final two semesters of the student’s graduating year. Most of the projects in the course include a significant laboratory experience and the student team works under the supervision of an instructor.

Curriculum’s Laboratory Component

Laboratory practice is incorporated in to courses from the freshman to senior years. Following are the courses in addition to basic sciences such as physics and chemistry that have a laboratory component and are a part of the core in the major: Biogeochemistry during the freshman year, Physical Geology and Principles in Environmental Engineering and Science during the sophomore year, Fluid Mechanics, Soils, Hydrology, Water Quality, and Air Quality during the junior year, and Water & Wastewater Treatment during the senior year level.

Air Quality and Air Pollution Control are two courses in the curriculum that focus on air and are mostly populated by juniors and seniors in the program, respectively. While both are three credit courses, lecture in the Air Quality course is supplemented with a laboratory component and the Air Pollution Control course is design-oriented in content. The focus of this paper is the Air Quality course, especially the laboratory component.

Elements of the Air Quality Course

Until the 2010-11 academic year the Air Quality course was formerly a four credit course with three hours of lectures and three hours of laboratory per week. For the past five years, it has been a three credit course consisting of two hours of lectures and three hours of laboratory per week. Some of the topics that were previously covered in lectures were converted to laboratory exercises. Successful completion of this course is a requirement for graduation and also serves as a prerequisite for the design course, Air Pollution Control, taken in the senior year. Typically by the time students take the Air Quality course, they would have completed two courses in calculus, two courses in calculus-based physics, a general chemistry course followed by a course in biogeochemistry, an introductory course on the fundamentals of environmental engineering and science, engineering thermodynamics, and fluid mechanics among others.

The course focuses on providing a basic understanding of air pollutants, and their behavior and effects on the environment and especially the atmosphere; it also considers original regulations such as the original and the many subsequent changes to the Clean Air Act Amendments, in resolving the problem of air pollution. Lecture topics include a brief history of air pollution, differences between the natural and polluted atmosphere, scales of air pollution problems, philosophy of air pollution control, sources of pollutants and emission inventory, effects on human health and welfare, and impacts on vegetation and animals, on materials and structures, on the atmosphere, and on soil and water bodies. The lectures also cover long-term pollution effects, atmospheric chemistry, air quality criteria and standards, ambient air sampling, analysis and measurement of air pollutants, monitoring and surveillance, transport and fate of contaminants, regulatory control and organizations for air pollution control, indoor air pollution, and mobile sources.

Course's Laboratory Component

Laboratory sections have varied between 12 and 15 students during the past 10-12 years. This is a major factor for the success of the course as it has made it possible for the program to provide students with hands-on experience by working on projects that focus on collection, analysis, and interpretation of data using various instruments and computational tools. As mentioned earlier, the program criteria for accreditation requires that the program curriculum prepare graduates to conduct laboratory experiments and analyze and interpret the resulting data in more than one major environmental engineering focus areas. The ENV program is one of the few accredited programs that provide opportunities for the students to become proficient in conducting laboratory experiments and in analyzing and interpreting generated data in environmental engineering focus areas of air, water, and soil. Following are the course objectives that relate directly to the laboratory component:

(i) to conduct laboratory analyses of air samples and to interpret the analytical data that were generated
(ii) to provide a basic understanding of air pollutant dispersion in the atmosphere and introduce students to concepts in dispersion modeling using a quantitative approach.

Laboratory work includes both problem-oriented exercises and hands-on experiments using various air monitoring instruments and equipment. These exercises begin with an introduction to lab safety and a quiz based on the lab safety video that the students are required to watch in the first class. This class is followed, during the next few weeks, with (i) problem-solving exercises that emphasize on the application of basic gas behavior concepts in expressing concentrations of air pollutants; (ii) analysis and presentation of air quality data; and (iii) an introduction to meteorology relevant to air quality and estimating pollutant concentrations from stationary and line sources using mathematical models and software. In addition, one of the goals of the course is to have a field visit to a facility where students observe air quality sampling and measurement practices and depending on the site, also see some of the air pollution abatement systems in operation.

Over the past two accreditation cycles, individual and group projects assigned to students include calibration of sampling pumps, evaluation of the ventilation systems in selected classroom buildings, monitoring indoor and ambient air quality along with noise level and light intensity monitoring. Computer-based exercises include the use of dispersion models such as the Industrial Source Complex (ISC) and AERMOD to estimate the regulatory design pollutant concentrations under a variety of atmospheric and emission conditions.

In the sampling exercise, students work in groups of four to six and select two sampling sites, one indoor and one outdoor, and they start by providing a sampling schedule to the instructor and to other students in the class. In addition, each team provides a list of parameters and methods for air quality sampling and analysis to the instructor to receive permission to proceed with their project. This ensures that all student groups would have access to the instruments and equipment that they would need. This also emphasizes the importance of planning and scheduling while working on a project as a team. The university's library, kitchen in the school's main cafeteria, an intermodal transportation facility in a downtown area, a barbeque restaurant near the university, residence halls and private residences, and major intersections near the university have been some of the sites chosen by students to complete their projects. Tedlar bags, Summa canisters, and Gastec and Dräger samplers and analyzers were typically used for sampling and analysis. Some of the other instruments that have been used in the recent (past seven) years for sampling and monitoring various air pollutants include SKC Cascade Impactors for particulate matter, TSI Inc.'s P-Trak Ultrafine Particle Counter, Sabio Instruments Inc.'s Photometer for ozone, RAE Systems QRAE II Personal Air Monitor for carbon dioxide, hydrogen sulfide, and other combustible gases, Extech Sound Level Meters for noise levels, and Test Light Meters for light intensity. For parameters that could not be analyzed on campus such as radon and diesel particulate matter (DPM), sampling cartridges were mailed to commercial analytical laboratories suggested by the vendors.

In another project offered every year in the course since 2000, mathematical models and air sampling instruments were used to determine the ventilation and air exchange rates in chosen classrooms, laboratories, and offices. Gas detectors for carbon dioxide, carbon monoxide, particulate matter samplers, Dräger air current kits, Davis Instruments anemometers, Testo Fiber Optic Scope and psychrometers were used by students to estimate the concentration of gaseous pollutants, temperature, and relative humidity indoors under varying conditions of occupancy at the sampling sites.

In both projects mentioned above, students compared their results to existing NAAQS and ASHRAE standards where appropriate. Students choose either or both indoor and outdoor sites for monitoring to determine if the air quality meets the occupational health standards for indoor air and the National Ambient Air Quality Standards (NAAQS) for selected criteria air pollutants at outdoor sites. During the final two weeks of the class, students presented their findings in a report to the instructor and as a presentation to the class.

In addition, typically one laboratory class period is dedicated to discuss ethical and professional responsibilities using air pollution-related case studies. Since the course is offered during the spring semester, weather conditions have made it difficult to have field visits on a regular basis. Recent field trips include a cogeneration plant, a pharmaceutical plant, and the state's air quality monitoring stations. It must also be noted that until May 2014, many of the students in the course became members of the Air & Waste Management Association (AWMA). The course has also provided opportunities for students to pursue the capstone senior design project in the field of air quality and air pollution control.

Student Outcomes and Assessment

All required environmental engineering courses in the program have published, in the course syllabus, specific learning objectives and their relationship to ABET EAC Criterion 3 Student Outcomes (a-k) that the ENV program has adopted.

The ENV program has adopted the ABET student outcomes that each graduate of the ENV program should be able to demonstrate and are listed below:

(a) an ability to apply knowledge of mathematics, science, and engineering
(b) an ability to design and conduct experiments, as well as to analyze and interpret data
(c) 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
(d) an ability to function on multidisciplinary teams
(e) an ability to identify, formulate, and solve engineering problems
(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, economic, environmental, and societal context
(i) a recognition of the need for, and an ability to engage in life-long learning
(j) a knowledge of contemporary issues
(k) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.

The Air Quality course is designed to address many, but not all, of these outcomes and at different levels. The specific course outcomes anticipated by successful completion of the course are listed below. This statement of course outcomes provides a broader perspective on the overall objectives of the course.

Outcomes a and e are central to the course. Atmospheric chemistry is the basis of many analytical measurements and treatment technologies. Knowledge of calculus is applied in dispersion modeling and in performing material and energy balances. Much of the homework emphasizes the application of various basic science and engineering concepts used in quantitative and qualitative analyses of air sampling.

Outcomes b and k are the focus of the laboratory component of the course. Use of computer and mathematical models and laboratory exercises involve standard analytical procedures, evaluation of experimental errors, and interpretation of the data and model output. Even though the emphasis is on conducting experiments and collecting, analyzing and interpreting data, principles of experimental design are also included in the class projects; experiments are designed to determine the effect of altering parameters such as classroom occupancy and room temperature on the indoor air quality and the air ventilation rates at indoor sampling sites and to consider realistic constraints such as time, money, and site conditions in completing the project.

Outcomes d and e are addressed in the limited homework problems that address global and local issues, and by group work in the laboratory.

Outcomes f, h, i, and j are frequently considered in the class discussions of articles in current research journals and magazines (e.g., AWMA's Research Journal, and Environmental Manager magazine) and during discussions of the environmental impact of different pollution control strategies (e.g., pollution prevention vs. treatment).

Outcome g is addressed in written form via laboratory and other reports, and in oral form via presentations.

In the most recent accreditation cycle, the ENV program used eight different assessment measurement tools of which two tools *viz*., Embedded Indicators and Student Course Assessment were used to measure student outcome attainment in the Air Quality course; both of these provide quantitative data to evaluate the level of compliance. Results from the FE examination in the air quality-specific topic area are used to evaluate the performance of students by comparing their performance to the "ABET Comparator Average Performance Index" as reported in NCEES' Subject Matter Report made available through the examining organizations' institution reports.

Embedded indicators are exercises that students complete in a course to attain the course's learning objectives and specific student outcomes. Instructor course evaluation using Embedded Indicators was incorporated in some courses including Air Quality during the previous accreditation cycle. The Student Course Assessment is a tool that has been in use for twelve years and involves students completing a Course Assessment Survey during the final week of classes. Students assess the course learning objectives and student outcomes using a rating scale of 0-5 (0 = Not Achieved and 5 = Well Achieved). Each instructor sets his or her own criteria for evaluating the objectives and outcomes. Based on the data and student comments, appropriate changes are made to the course content and student activities including class projects, assignments, and laboratory exercises.

Embedded Indicators: This measurement tool was used to assess student outcomes a, b, h, and k in the Air Quality course.

Achievement of student outcome a was demonstrated through problem solving in laboratory exercises in basic gas concepts and noise pollution, and by the analysis and interpretation of regional and national air quality data. An expected level of attainment of 70% of the students scoring at least 75% was achieved during the most recent accreditation cycle.

Achievement of student outcome b was demonstrated by the students' ability to conduct experiments and analyze and interpret data by evaluating ventilation rates and assessing indoor air quality in teaching classrooms, offices, and the library on campus. An expected level of attainment of 70% of the students scoring at least 80% was achieved during the most recent accreditation cycle. One of the changes that has resulted from student evaluation and course assessment is the number of students assigned to each group in team exercises. Four to five students per group was found to be effective for proper student interaction and for carrying out self-assigned tasks. This would also assist in assessing Student Outcome d.

Achievement of student outcome h was demonstrated by students' performance on a written discussion on the impact of fracking on the environment and the society in general. This was a part of the lecture portion of the course and not related to the lab. An expected level of attainment of 75% of the students scoring at least 75% was achieved during the most recent accreditation cycle.

Achievement of student outcome k was demonstrated by students' ability to estimate downwind concentrations of pollutants at a specific location using dispersion models such as ISC and AERMOD. It must be noted that these regulatory models are complex for use at an undergraduate level and that the course attempts to provide an introduction to the basic capabilities of these models. All students were required to use the Breeze AERMOD software to estimate the concentrations of specified air pollutants under specific atmospheric conditions and submit the program output. This measure was achieved during the most recent accreditation cycle.

FE Examination Results: This measurement tool was used to assess student outcomes a and e in the Air Quality course.

Achievement of student outcomes a and e was based on students achieving 80% of the 2-year rolling national average on specific sections of the examination. These sections include mathematics, chemistry, thermodynamics, water resources engineering and air quality engineering for student outcome a and water resources, air quality, and solid and hazardous waste for student outcome e. It must be noted that the format of the FE examination and reporting changed during the previous accreditation cycle. The ENV program, as mentioned earlier, requires graduating students to have taken the exam before graduation but not necessarily pass it; with the number of students taking the examination varying from 6 to 14 during the most recent accreditation cycle, it is difficult to consistently meet a performance criteria of equaling or exceeding the 80% of the national average or an ABET Comparator Average Performance Index of 0.85 in selected sections of the exam. Since spring 2014 when the administration of the newly formatted FE examination started by NCEES, the ABET Comparator Average Performance Index for Air Quality has consistently been in the 0.85-0.95 range.

Student Course Assessment: This measurement tool was used to assess student outcomes d, f, i, and j in the Air Quality course.

While the student evaluations indicated that all except student outcome d met the expected level of attainment of an average score of 4.0 or better, the program faculty identified this measurement tool to be "less objective." This measurement tool has not been utilized in the Air Quality course for a couple years.

Conclusion

The ENV program is "laboratory-heavy" as most of the junior and senior level courses have a laboratory component supplementing the lectures. Nine courses in the environmental engineering and environmental science that are required for graduation have laboratory sections in addition to lectures. The program faculty strongly believes that the laboratory component to be one of the major strengths of the program. The accredited program is one of the very few across the country to offer a required course in air quality that has a strong laboratory component. Alumni surveys also indicate that many graduates of the program have been employed in air-related fields over the years. Increasing enrollment in the course has provided challenges and opportunities to improve the course. For example field visits to facilities practicing air sampling and with air pollution control systems is one the course objectives but has been sporadic over the last five years due to weather conditions and other logistics. Although these developments have the potential to challenge the department resources, the attainment of the ABET EAC Student Outcome b and satisfying the program criteria relating to laboratory experience in air as one of the focus areas, are in sound condition and can serve as a model for other programs.

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