121st ASEE Annual Conference & Exposition
Indianapolis, IN
June 15-18, 2014
Paper ID #10533

Use of in-class demonstrations and activities to convey fundamentals of environmental engineering to undergraduate students

Prof. Natalie Mladenov, Kansas State University

Dr. Natalie Mladenov is an assistant professor in the Department of Civil Engineering at Kansas State University. She teaches environmental engineering courses including Environmental Engineering Fundamentals and Sustainable Water and Sanitation Systems. Dr. Mladenov has a keen interest in issues related to water, sanitation, and sustainability in the developed and developing world.

Dr. Tara Kulkarni, Norwich University

Dr. Tara Kulkarni is an Assistant Professor in the Department of Civil and Environmental Engineering at Norwich University. She teaches introductory environmental engineering courses including Sanitary Engineering, and Water and Wastewater Treatment.

Dr. Mara London, Gonzaga University

Dr. Mara London is an assistant professor in the Department of Civil Engineering at Gonzaga University. She teaches introductory and advanced undergraduate courses in Environmental Engineering, focusing on water quality and treatment.

Use of in-class demonstrations and activities to convey fundamentals of environmental engineering to undergraduate students

1. Introduction

Awareness of diverse learning styles is now recognized to be a critical step toward producing effective learning experiences for students. Different learning styles were categorized by Felder and Silverman[1] in the Index of Learning Styles (ILS) classification system based on student perception and understanding of information (Figure 1). In the ILS system, student learning falls within a continuum represented by various types of students: students who favor receiving information from their senses, by observation, experimentation, and repetition (sensory) and students who prefer having information come to them through memory, imagination, theory, and hunches (intuitive); students who prefer receiving information through physical demonstration, figures, and pictures (visual) or through words and mathematical expressions (verbal); students who process information actively through hands-on experiences (active) and those who reflect on information (reflective); and students who learn in step-by-step logical progression (sequential) and those who get the message all at once without seeing the connections (global). Estes et al.[2] revealed that traditional lecture-style engineering courses tend to teach toward the intuitive, verbal, reflective, and sequential learner. In contrast, recent work by Felder and Spurlin[3] suggests that many engineering students are predominantly sensory, active, visual, and sequential whereas engineering faculty tend to be more reflective, intuitive and global in their learning (Figure 1). Therefore, recognizing these disparities between traditional engineering teaching, teacher learning styles, and student learning styles is an important step toward improving learning in the engineering classroom. Adding active learning to the classroom is one method that has been shown to enhance learning[4], with physical in-class demonstrations being especially effective for engineering education[5].

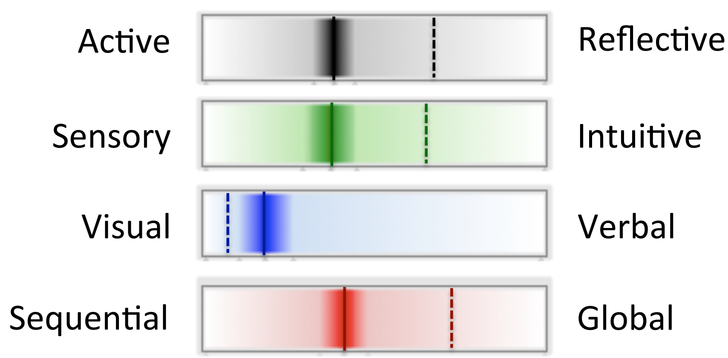

Figure 1. Preference for learning styles by engineering students (solid line and shading represent mean value and standard deviation, respectively), and dashed lines correspond to preference by engineering faculty[3].

Researchers and practitioners in the area of engineering education have also used Bloom's Taxonomy directly and indirectly in the development and implementation of their teaching styles in congruence with student learning styles. Bloom's Taxonomy, based on six increasing levels of complexity, encompasses knowledge, comprehension, application, analysis, synthesis, and evaluation[6,7]. Through the ExCEEd Teaching Workshop, educators learn to develop learning objectives and content that promotes Bloom's Taxonomy[2].

At the undergraduate level, environmental engineering is often a core area within civil engineering or chemical engineering, biological engineering, and other related engineering majors or a separate and distinct major. Introductory environmental engineering courses aim to convey a process-level understanding of biological, physical, and chemical processes in various types of environmental media (primarily air, soil, and water environments)[8]. The learning outcomes of an environmental engineering course also prepare students for future courses that address sustainability and may have treatment design components, including the treatment of water, wastewater, solid and hazardous wastes, and air pollutants. The introductory environmental engineering course thus deals with diverse material that may be well suited to sensory, active, and visual learning styles and capable of addressing multiple levels of Bloom's Taxonomy.

To gage student interest in the diverse suite of topics in environmental engineering and enhance student learning of fundamental environmental engineering concepts, a series of dynamic, in-class activities has been compiled by educators at three ABET-accredited undergraduate-serving institutions. Previously, the instructors had used think-pair-share activities and group efforts to solve short numerical problems, but little else. In this study, instructors added new in-class activities to the environmental engineering curriculum, which were grouped into the following categories: demonstrations, competitive activities, multimedia activities, and group experimental and problem-solving activities. This paper describes the goals and key elements of these activities as well as a qualitative evaluation of their effectiveness in introductory environmental engineering courses at the three different institutions.

2. Methods

New activities were developed in courses that previously used little to no additional activities. In-class activities were developed based on principles learned by all three educators at the Excellence in Civil Engineering Education (ExCEEd) Teaching Program[2], a teacher-training program of the American Society of Civil Engineers (ASCE). Figure 2 provides an overview of the ExCEED model[2], used by each instructor as a basis for developing most of the in-class activities.

The in-class activities presented here are categorized into four types: 1) demonstrations conducted primarily by the instructor to illustrate key concepts, 2) competitive activities, such as games and scavenger hunts, 3) multi-media activities such as the use of videos and music, and 4) group problem solving activities that included experimental or design problems. These activities address various learning styles and different aspects of Bloom's Taxonomy.

Teacher as a role model

- Structured organization
  - **Based on learning objectives**
  - **Appropriate to the subject matter**
  - Varied, to appeal to different learning styles
- **Engaging presentation**
  - Clear written and verbal communication
  - **High degree of contact with students**
  - **Physical models and demonstrations**
- **Enthusiasm**
- Positive rapport with students
- Frequent assessment of student learning
  - Classroom assessment techniques
  - Out-of-class homework and projects
- **Appropriate use of technology**

Figure 2. The ExCEEd model[2] with key elements used for in-class activities emphasized in bold type.

The three introductory courses of this study all included an introduction to the following topics: Environmental Chemistry, Mass Balances, Risk Assessment, Water Quality (including dissolved oxygen and biochemical oxygen demand, and water pollutants), Water Treatment, Wastewater Treatment, and Air Quality. The class at Institution A had 23 Civil and Environmental Engineering seniors and was held three times per week for 50 minutes each with a weekly 3-hour lab. At Institution B, the class had 23 juniors and seniors, mostly from Civil Engineering but also from Biological and Agricultural Engineering, and was held twice per week for 50 minutes with a weekly 3-hour lab. At Institution C, two sections were held three times per week for 50 minutes with 23-30 juniors and seniors in each section, including students from Civil Engineering and Engineering Management. At all three institutions, the introductory course in Environmental Engineering was required for an undergraduate degree in Civil Engineering.

To qualitatively assess the in-class activities, we provide our perspectives as instructors and informal feedback that we received from students. Survey results presented were excerpted from Institutional Review Board-approved surveys. Teaching evaluations and performance on final exams were used to more quantitatively gauge changes in student response to the new teaching techniques. To determine significant difference between two sample sets, a two-tailed t-test with equal variance was used, and p values less than 0.05 were considered significant. Informal student feedback as well as verbal and nonverbal cues from students provided a basis for modifying certain activities.

3. Results and Discussion

3.1 Activities Developed

The environmental engineering activities covered concepts ranging from understanding mass balance in reactors to designing environmental management systems. Activities were developed to promote learning through different levels of Bloom's Taxonomy. The categories of in-class activities that were developed and short examples and descriptions of each are given below (Tables 1 through 4).

Demonstrations. Demonstrations targeted sensory and visual learning styles (Table 1). These instructor-led activities were often viewed in a central location in the classroom or as visuals or models that could be passed around the classroom. The following positive aspects of demonstrations were observed by the instructors: the demonstrations opened the door for in-class discussion; students made an immediate connection with concepts conveyed in class; demonstrations typically lasted no more than 5-10 minutes; supplies and materials needed were typically low-cost and readily-available. Means for improving demonstrations included practicing for smoother flow, moving around the classroom so that all students could see the demonstration, calling on "volunteers" or finding ways to more actively involve the students in the demonstration, and purposefully laying out the key learning outcomes and concepts that would be assessed.

Table 1. Description of in-class ***demonstration*** activities used in introductory Environmental Engineering courses in Fall 2013.

Title	*Description*	*Concepts addressed*	*Learning styles*	*Bloom's Taxonomy*	*Assessment performed?*
Which one would you drink?	One beaker of water with mulch and leaves and one with clear water from unknown source (tap or toilet) passed around classroom.	Concentration, scale, batch reactors, water quality, Safe Drinking Water Act	Sensory, visual, active	Comprehension, application	Assignments and short answer test questions
Completely mixed batch reactors	Used a beaker, food color and water or coffee and cream, and a stirrer to demonstrate a completely mixed batch reactor.	Batch reactors and related kinetics	Visual, sensory	Comprehension, application	Assignments and exam questions on the quantitative aspects of batch reactors.

Competitive. This category of in-class activity had teams compete for points in an answer-question game modeled after the popular television show, Jeopardy (Table 2). Students had very positive opinions of this activity and said they preferred this type of assessment. These activities address lower levels of Bloom's Taxonomy, knowledge and comprehension, and are particularly well-suited for engaging students in content that required comprehension and memorization (e.g., learning about legislation or technical terminology) as opposed to calculations or design. Some important considerations included ensuring that all teams have the same opportunities for full points and finding ways for students to take notes during the games so that they could review those notes for assignments or exams. Although competitive activities were generally enjoyed by students, they did use up most or all of the class time.

Multimedia. Multimedia activities (Table 3) included short videos that were very effective at illustrating concepts for the visual and sensory learner and could be strategically inserted at many points in the class. Some videos provided a virtual tour of technologies and systems (e.g., recycling center) that the class was unable to visit due to time and other constraints. To address the possibility that students may drift off or disengage from the video for various reasons, adding a quiz/questionnaire based on what students viewed in the video encouraged active engagement with the content of the video.

From time to time, music chosen by the instructor or students was played at the start of class. In one class, students were polled about their favorite bands in the first week of the course. Instructors also occasionally played music aligned with course content (e.g. a song with "heat" in the title was played when enthalpy was covered). This had the effect of breaking down instructor-student barriers and setting a more relaxed atmosphere for learning.

Table 2. Description of an in-class ***competitive*** activity used in introductory Environmental Engineering courses in Fall 2013.

Title	*Description*	*Concepts addressed*	*Learning styles*	*Bloom's Taxonomy*	*Assessment performed?*
Jeopardy quiz	Teams compete in jeopardy-style quiz	Clean Air Act, air pollutants, hazardous waste	Verbal, active	Knowledge, comprehen-sion	Multiple choice and short answer exam questions.

Group problem solving and experimental activities. Think-pair-share and group efforts to solve short numerical problems in class had been part of the courses in previous semesters. The new group experiments and group design activities (Table 4) that were added enhanced learning on multiple levels and were especially effective for promoting active learning in the classroom. All instructors agreed that the new group activities made new connections to content or reinforced knowledge students already had. Experimental activities allowed students to formulate hypotheses based on their existing knowledge from the course. Design activities, especially those in which each team member was a unique content expert, brought students closer to real-world engineering design. Therefore, the design activities, in particular, increased the rigor of the course and promoted synthesis and evaluation, the highest levels of Bloom's Taxonomy.

In developing these activities, however, some transformation in accepting the activity and deviating from the traditional lecture-style class was needed on the part of the student. For example, during the development of concept sketches for the environmental management systems, students were provided with poster sized paper and markers, which caused some students to think of the activity as "silly" or of "grade-school level". However, as the groups started developing the sketches and conversation flowed easily, there was a general consensus among students that the schematics did help them see the interrelationships between various environmental systems more clearly.

Table 3. Description of in-class ***multi-media*** activities used in introductory Environmental Engineering (EE) courses in Fall 2013.

Title	*Description*	*Concepts addressed*	*Learning styles*	*Bloom's Taxonomy*	*Assessment performed?*
Videos	Students watch videos on waste-to-energy, zero-sort recycling, landfill orchestra, water and waste in developing communities, environmental disasters, etc.	Air, water, wastewater, hazardous waste, and noise	Sensory, visual	Knowledge, comprehen-sion, application	Concepts were mainly evaluated in assignments, exams and short questionnaires over video content.
Online discussion forum	Students lead a 10 – 15 minute discussion on a current environmental engineering topic.	Air, water, waste, noise, and other general EE topics	Reflective	Analysis, synthesis, evaluation	Discussion forum posts and responses were graded on a rubric – worth 5% of course grade.
Friday news roundup	Students research and post news items related to a country and state that they were assigned. These were discussed in class on Fridays.	Contemporary issues in EE	Reflective	Synthesis	Posts counted toward a third of the participation grades.
Music	Played at start of class as students arrive.	Various themes	Sensory	N/A	N/A

Table 4. Description of in-class ***group problem solving and experimental*** activities used in introductory Environmental Engineering courses in Fall 2013.

Title	*Description*	*Concepts addressed*	*Learning styles*	*Bloom's Taxonomy*	*Assessment performed?*
Rubber egg	Teams submerge their raw egg into solutions of vinegar or water for several days, measure pH before and after, and formulate hypotheses.	Carbonate system, Ideal Gas Law, solubility, pH, climate change	Sensory, visual, sequential, active	Application, analysis, synthesis	Assignment evaluating knowledge of carbonate system to explain changes in egg.
Drinking Water Taste Test	Students rate unlabeled water samples (tap, bottled, filtered) based on aesthetic characteristics and guess the water source.	Drinking water regulations (FDA, EPA), cost of water, and physio-chemical and biological characteristics of drinking water.	Sensory, visual, sequential, active	Knowledge, comprehension	Students researched and summarized hometown municipal water treatment train, and drinking water quality report.
Landfill S'mores*	Students make S'mores as an analogy to the various layers in a landfill. The marshmallows represent the waste placed in layers, while the graham crackers represent the liner system and the chocolate represents the soil covers.	Landfill liners, leachate pipes, waste placement, and daily and final covers	Sensory, visual, active	Comprehension, application	Landfill design calculations assignments based on conceptual understanding.
Environmental Management Systems (EMS) jigsaw	Students develop concept sketches** for air, water, and waste management systems in 3 "expert" groups; groups are then re-formed with at least one air, water, and waste expert in each and concept sketches for a comprehensive EMS are developed based on combined expertise.	Key aspects of air, and water resources and land management systems – individually and in combination.	Sensory, visual, sequential, active	Application, analysis, synthesis, evaluation	Assignment question on ISO 14001 EMS.

* Source: P. Omur-Ozbek, ExCEEd Teaching Workshop, 2013.

** Concept sketch = diagram/figure used to depict processes, concepts and interrelationships.

3.2 Assessment

Compared to previous semesters in which little to no additional activities were used, the combined use of different activities in Table 1 had a positive effect at all three institutions. This positive effect was captured by the instructors in qualitative assessments of student attitudes, described in greater detail above. The benefits of using in-class activities may also have contributed, at least partially, to each instructor's overall teaching evaluations, which improved by 5.3% at Institution A, 10.5% at Institution B, and 20.3% at Institution C over the previous semester.

At Institution A, students were asked to rate ten different activities that were used to support the curricular content, both in class and out of class. These ranged from videos and PowerPoint presentations shown in class to support class content to field trips. The top three choices of in class activities for the 16 students who participated in the survey were videos, use of concept sketches, and Jeopardy style quizzes.

At Institution B, the instructor evaluated the effectiveness of the Jeopardy Air Quality quiz by comparing scores on five short-answer final exam questions related to air quality in Spring 2013 before undertaking the in-class activity to scores in Fall 2013 after the in-class activity was used. Twenty-two out of 23 students participated in the Jeopardy quiz in Fall 2013. In the spring semester, before in-class activities were used, only 2 out of 32 students (6% of students) answered all five air quality questions on the final exam correctly and the mean score for those questions was 63%. In the fall semester, 9 out of 23 students (39%) answered all questions correctly and the mean score for those questions was 79%. This 16% improvement over the spring 2013 performance was statistically significant ($p = 0.01$). In both semesters, student access to previous exams, class notes, and other material was essentially equal.

3.3 Considerations

In the absence of pre-assessment data, evaluating the effectiveness of in-class activities is inherently challenging. The results of the assessment using the Jeopardy Air Quality activity suggest that familiarity with air quality terms and concepts through the competitive Jeopardy format may have reinforced learning and contributed to the higher scores in the fall semester. However, a number of factors, including smaller room, smaller class size, and other ExCEEd-related improvements to the course may have contributed to the improved scores.

The higher ratings of teaching effectiveness for each instructor suggest that the use of in-class activities contributed to better teaching. However, it is important to recognize that higher ratings were undoubtedly influenced by other changes the instructors made based on what they learned in the ExCEEd Teaching Workshop. For example, all instructors decreased their reliance on Powerpoint slides, identified and clearly stated the learning objectives for each lesson, and made greater efforts to interact with and engage students. At Institution C, teaching evaluations may have also been influenced by changes in the course assessment structure: students were given more frequent assignments, and regular quizzes replaced the traditional exam structure. Nevertheless, accepting that the use of in-class activities is a factor contributing to teaching evaluations, the positive feedback from students suggests that the effect was a positive one.

The instructors did find that the classes they augmented with in-class activities required more planning time than conventional lectures with limited activities. However, the initial investment in time is likely to be cut substantially the next time the activity is used, as instructors gain experience and confidence. For example, planning the rubber egg activity (Table 4) in Fall 2013 required time for acquisition of materials, set up of the demo, development of lecture notes to tie in to course content on the carbonate system, and rehearsal with the activity to ensure it would produce anticipated results, a total of ~ 1.5 hours committed to preparing for the activity. In the spring 2014 semester, the amount of class preparation devoted to this activity was approximately 20 minutes.

4. Conclusions

In general, student attitudes indicated they were receptive to the use of demonstrations, videos and other in-class activities. Comments received and survey results confirmed this observation. Teaching evaluations and exam performance further suggest that the use of in-class activities had a positive influence on student learning.

Peer feedback and mentoring among the three collaborating faculty resulted in development, revision, and refinement of activities, which improved the quality of in-class activities. For the instructors, the combination of group and individual activities as well as competitive and non-competitive tasks allowed various learning styles to be addressed. Students had various options to score better in areas that were mapped directly to the learning styles to which they were drawn compared to others that were not as effective for them. Group and experimental activities, in particular, increased rigor of the course by promoting higher levels of Bloom’s Taxonomy.

References cited:

1. Felder, R.M. and Silverman, L.K. (1988). Learning and teaching styles in engineering education [Electronic Version]. *Engr. Education, 78(7), 674-681.*
2. Estes, A. C., Welch, R. W., and Ressler, S. J. (2005). The ExCEEd teaching model. *Journal of Professional Issues in Engineering Education and Practice*, *131*(4), 218-222.
3. Felder, R. M., and Spurlin, J. (2005). Applications, Reliability and Validity of the Index of Learning Styles. *Int. J. Engng Ed.* Vol. 21, No. 1, pp. 103-112, 2005.
4. Campbell, M. (1999). “Oh, now I get it!” *Proceedings of the 1999 American Society of Engineering Education Annual Conference and Exposition*, American Society for Engineering Education, June 1999.
5. Lowman, J. (1995). *Mastering the Techniques of Teaching*. Jossey-Bass, San Francisco, CA, USA, 1995, pp. 132.
6. Bloom B. S. (1956). *Taxonomy of Educational Objectives, Handbook I: The Cognitive Domain.* New York: David McKay Co Inc.
7. Anderson, L. W., Krathwohl, D. R., Airasian, P. W., Cruikshank, K. A., Mayer, R. E., Pintrich, P. R., Raths, J., Wittrock, M. C. (2000). *A Taxonomy for Learning, Teaching, and Assessing: A revision of Bloom's Taxonomy of Educational Objectives*. New York: Pearson, Allyn & Bacon.
8. Environmental Engineering Body of Knowledge Task Force. (2009). *Environmental Engineering Body of Knowledge*. American Academy of Environmental Engineers (AAEE), Annapolis, MD, USA.