Hands-On Learning of Water Treatment Design

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Abstract

The Environmental Process and Simulation Center (EPSC) was created at Michigan Technological University (MTU) with the aim of enhancing understanding of physical, chemical, and biological processes used in environmental engineering applications. In 2004, a hands-on design course for undergraduate environmental engineering students was offered for the first time utilizing MTU's EPSC; the goal of this course was to provide students with valuable experiences of designing, operating, and analyzing treatment systems. Lessons learned in 2004 were applied to modify the course structure and assessment plan for the following year. The assessment plans along with the course objectives were critiqued using Bloom's Taxonomy. The results of this evaluation led to recommendations for further refinement of the course.

Introduction

A hands-on course focusing on the design of treatment systems was created at Michigan Technological University (MTU) with the aim of enhancing the transition of environmental engineering graduates into the workplace, as smooth transitions are lacking according to professionals from the field. This course (i.e., EPSC course) is held in the newly constructed Environmental Process and Simulation Center (EPSC), which was funded by the National Science Foundation (NSF), by industry partners of Dow, DuPont, Fisher-Rosemount, and Pepperl+Fuchs, and by MTU. The purpose of this paper is two-fold; it seeks to explore and evaluate assessment techniques and to determine if the EPSC course does indeed smooth the transition of graduates into the workplace.

The EPSC is a Unit Operations Laboratory (UOL) containing the following laboratory- or pilot-scale processes: (1) activated carbon adsorption, (2) advanced oxidation, (3) air stripping utilizing a packed tower, (4) ion exchange, (5) jar testing for coagulation/flocculation/ sedimentation system optimization, (6) activated sludge treatment using sequencing batch reactors (SBRs), and (7) a drinking water treatment plant (Table 1). The primary goal of the EPSC was to provide students with hands-on experience that allows them to apply the theory they have previously covered in other courses to real-world design scenarios; for this course, hands-on experience is defined as basic working knowledge of the environmental processes currently used in industry for air and water treatment[1]. This valuable exposure includes operating and analyzing some of EPA's Best Available Treatment (BAT) and Best Conventional

Table 1: Description of unit processes found in the EPSC.

Unit Process	Technology Description	EPA BAT[a]	Type of Contaminants Removed	Process Controlled
Activated Carbon Adsorption	Utilizing activated carbon to remove chemicals from a fluid (liquid or gas); this removal is due to the chemicals adsorbing to the carbon.	Classified as a BAT for a wide variety of contaminants in water including Synthetic Organic Chemical (SOC) and VOCs.	soluble organics and inorganic compounds (nitrogen, sulfides, heavy metals)	no
Advanced Oxidation	Oxidizing complex contaminants by using the hydroxyl radical; simpler end products are the result of this process.	Classified as a BAT for water contaminated with SOCs.	organics that are difficult to degrade biologically	no
Air Stripping	Transferring of a chemical from contaminated water to an initially-clean gas.	Classified as a BAT for water contaminated with volatile organic chemicals (VOCs).	volatile chemicals	yes
Drinking Water Treatment Plant	Removing contaminants using direct filtration followed by UV disinfection.		particles, bacteria, viruses	yes
Ion Exchange	Displacing ions of a given species from an insoluble exchange material (resin) by ions of a different species in solution.	Classified as a BAT for metals such as arsenic and nickel.	heavy metals	no
Jar Testing	Adding a chemical to destabilize the suspended solids in water to promote particle growth (coagulation), stirring the water to increase the frequency of particle collisions to promote growth (flocculation), and removing particles from water by gravity separation (sedimentation).		suspended solids (turbidity), color	no
SBRs	Operating a fill-and-draw reactor for activated-sludge treatment. The system is aerated in order to keep the microorganisms responsible for treatment in suspension and to add the required oxygen; after aeration is complete, the solids (biomass) are settled out.		organics, nitrogen, phosphorus	yes

[a]Best Available Technology

Sources:

Metcalf & Eddy, Inc. Wastewater Engineering: Treatment and Reuse. 4th Edition. McGraw Hill: Boston, 2003.

U.S. Environmental Protection Agency. www.epa.gov

Treatment (BCT) technologies and utilizing state of the art industrial process control equipment to operate selected unit processes.

MTU's environmental engineering bachelor's of science program is one of the 47 undergraduate environmental engineering programs that are currently accredited by ABET[2], and MTU's program has been accredited since 1987. In 1997, ABET adopted Engineering Criteria 2000 (EC2000) with the purpose of continuously improving programs by creating program-specific missions and goals. EC2000 focuses on what is learned by the student rather than what is taught by the professor. The specific accreditation for environmental engineering programs includes, but is not limited to, the requirements of demonstrating that graduates have an ability to conduct laboratory experiments and to critically analyze and interpret data in more than one major environmental engineering focus areas (e.g., air, water, land, environmental health) and have an ability to perform engineering design by means of design experiences integrated throughout the professional component of the curriculum[3]. The EPSC course significantly contributes to the environmental engineering program's ability to fulfill the professional component of the ABET accreditation by providing students with hands-on opportunities to study the design, operation, and analysis of water and wastewater treatment systems. This hands-on learning experience has the potential to bridge the gap for graduates entering the workplace.

There are eight ABET accreditation criteria applied to engineering programs. Two of the criteria include requiring programs to demonstrate they meet the program educational objectives and the outcomes. Program educational objectives are statements that describe the expected accomplishments of graduates during the first several years following graduation from the program while program outcomes are statements that describe what students are expected to know or be able to do by the time of graduation from the program[3]. The six specific objectives of the EPSC course were for the students to:

- Apply the physical, chemical and biological fundamentals and process design approaches employed in water and wastewater treatment to pilot-plant operation of selected unit operations and to data analysis;
- Learn the fundamentals of process control and its application to selected water and wastewater unit processes;
- Operate selected individual unit processes, including process controlled activated sludge SBRs, process controlled air stripper with off-gas control, liquid-phase adsorption, chemical dosing with jar testing, and ion exchange;
- Apply wet chemistry and analytical instrumentation techniques for measuring water quality parameters;
- Evaluate and compare pilot-plant data with process modeling techniques;
- Learn laboratory safety procedures[4].

The course officially started in the spring semester of 2004 with 26 students enrolled, of which the majority were women (64%). During the spring 2005 semester, 21 students enrolled, of which 48% were women. In both of the courses, students were exposed to five out of the seven unit processes: adsorption, air stripping, ion exchange, jar testing, and SBRs. The first-time course had the following structure:

- The first three class sessions included a course overview, laboratory safety training, lectures on the unit processes, excluding air stripping, an introduction to process control equipment, and demonstrations of laboratory analytical techniques.
- During the next eight class periods, the students worked in teams spending two periods on each of the four treatment systems; due to equipment limitation, each group worked on a different unit process in a given period. At the start of a new rotation, a team member from the previous group working with a given system helped explain the system operation to the new group; hence, students helped teach each other. Each team was required to submit a laboratory report after the completion of each unit process activity.
- The students regrouped as a class for the next session, in which they were introduced to the fundamentals of air stripping before designing, operating, and analyzing the pilot-scale packed aeration tower.
- For the final class period, each team presented a poster on a different unit process to members of the Civil and Environmental Engineering Professional Advisory Committee (CEEPAC).

Based of the findings of the 2004 educational assessment, the EPSC course structure was modified for the 2005 term as described below:

- The first class session consisted of a course overview, a pre-test assessment activity, and laboratory safety training. The pre-test assessment activity will provide a basis to measure the change in student skill, knowledge, and behavior as a result of their experiences in the EPSC course.
- The next ten class periods will occur in the laboratory setting with the students split into teams of two or three; every team will spend two weeks on each of the unit processes, which include adsorption, air stripping, ion exchange, jar testing, and SBRs. Since students will be faced with open-ended problems in future careers, a real-world scenario was presented for the students to design, operate, and analyze the effectiveness of a treatment system to remove a chemical of concern to a defined concentration.
- The final weeks of class will be devoted to a review and discussion of the course content. One week will focus on the teams working together to solve the overlying problem and optimize the system design. This structure will permit students to learn by doing, promote the style of teaching from exemplars to generalizations, and allow students to learn from each other; all of which are key principles for engineering design education[5,6]. The last week will be devoted to teams presenting posters on each unit process.

Since the EPSC is still in its pilot phase, evaluation of the center is crucial. Evaluation is defined as "a systematic investigation of the worth or merit of an object" by the Joint Committee on Standards for Educational Evaluation (1981)[7]. The purpose of the educational assessment is to reduce and eliminate the gap between what is taught by the professor and what is learned by the students. The assessment performed for the EPSC course took a modified form of a formative evaluation, which is defined by NSF as an assessment of ongoing project activities, beginning at the start of the project and continuing throughout the project life[8]. A formative evaluation typically starts with an implementation evaluation phase, which analyzes whether the project is following its proposal plan; this stage is followed by a progress evaluation, which determines the degree to which a project is meeting its goal at various times through the project life[7]. The

educational assessment of the 2004 and 2005 courses presented here represents a stage of the progress evaluation phase.

An assessment should include both direct and indirect measurements[9,10]. Direct measures of student learning are performance based, focusing on the actual work students have produced[15]; these measures should be evaluated by a set of defined criteria in order to improve the reliability (i.e., the consistency to measure the same behavior) of the technique[11]. Indirect measures are sources of assessment data used to supplement direct measures by providing information that may illuminate aspects of what the direct measures suggest about students' academic achievement by gauging the value of the learning experiences[9].

The variety of tools used to complete the assessment of the EPSC course can be classified according to Olds et al. (2005) as surveys, observations, and baseline data. A survey is a self-report instrument, typically designed to capture data that cannot be observed and is an example of a descriptive study, which describes the current state of a phenomenon[12]. The drawbacks of this method include: (1) data accuracy depends on the honesty of the subjects, (2) a valid survey is difficult to develop, and (3) low response rates can threaten the validity of the study[12,13]. Surveys typically only provide indirect measures of student learning; yet, if the survey combines questions from standardized and locally developed tests, direct measures of student learning are possible. However, caution must be taken when using standardized tests in order to ensure the specific learning objectives of a program are aligned with the outcomes of the test[9]. Questions on the survey may be open-ended or selected response; the responses to the questions may be analyzed qualitatively and quantitatively, respectfully. One example of an open-ended question includes the "muddiest point" technique; this technique focuses on the concepts that students do not understand rather than asking students what they know[14].

Observations, which are also classified as a descriptive study, can provide the examiner with direct measurements of students' performances and/or behaviors. In order to focus the data collected, and thereby eliminating the gathering of unnecessary data, an observation protocol is typically defined. Observations are a useful tool to capture behaviors that participants are unlikely to report; however, this method can be both time and labor intensive for the assessor[12], and the results obtained can be skewed by the biases of the evaluator.

Baseline data is a type of experimental study, which is a study that examines how a phenomenon changes as a result of an intervention[12]. Using the method of baseline data, information is collected before and after an intervention; thus, this technique provides a comparison group when a control group is not available[12]. The disadvantage of using this method is that this tool is considered "unrecognized", which may lead to uncontrolled variables affecting the validity of the results[12].

The validity of an assessment is a critical component. Validity is defined as "…the extent to which the assessment model represents a fair assessment of the aims"; this is sometimes termed as content or construct validity[13,15]. Another important aspect of validity is "…the extent to which the examiners and teachers felt confident that the model was providing a good assessment…" of the specified outcomes; this may be termed face validity[13].

Bloom's taxonomy can be used as a framework to guide and critique course objectives and/or assessment tools[8,14,16-20]. Many different taxonomy models have been developed in education, but Bloom's taxonomy has probably had the most impact of any model in the last three decades[19]. Bloom's taxonomy classifies learning into three domains: cognitive, affective, and psychomotor [Bloom et al., 1956]. Each domain is then further divided into levels of learning as shown in Table 2. The cognitive domain focuses on the knowledge gained by students and consists of six levels: knowledge, comprehension, application, analysis, synthesis, and evaluation. The affective domain is related to emotional responses to tasks and is broken into five levels: receiving, responding, valuing, organizing, and value characterizing. The psychomotor domain is linked to skill, or motor activity, and has six levels: reflex movements, basic fundamentals, perceptual abilities, physical abilities, skilled movements, and nondiscussive behaviors.

Table 2: The levels of Bloom's Taxonomy defined[21].

Cognitive Domain
Knowledge . Students have the ability to remember information.
Comprehension . Students understand the information and can explain it in their own words.
Application . Students use knowledge to solve real-life problems.
Analysis . Students break down complex information into smaller parts.
Synthesis . Students combine elements and create new information.
Evaluation . Students make good judgements and decisions.
Affective Domain
Receiving . Students become aware of or attend to something in the environment.
Responding . An experience motivates students to learn and display a new behavior.
Valuing . Students become involved in or committed to some experience.
Organizing . Students integrate & prioritize a new value into an already existing set of values.
Value characterizing . Students act in accordance with the value and are firmly committed to it.
Psychomotor Domain
Reflex movements . Students respond involuntarily without conscious thought to a stimulus.
Basic fundamentals . Students make basic voluntary movements towards a particular purpose.
Perceptual abilities . Students use senses (seeing, hearing, touching) to guide their skill efforts.
Physical abilities . Students develop general skills of endurance, strength, flexibility, and agility.
Skilled movements . Students perform complex physical skills with some degree of proficiency.
Nondiscussive behaviors . Students communicate feelings and emotions through bodily actions.

Bloom's taxonomy is thought of as a cumulative hierarchy; the framework is considered a hierarchy because the levels of learning are arranged in order of increasing complexity and is considered to be cumulative because each level of learning is presumed to encompass all of the less complex levels (Kreitzer and Madaus, 1994)[20]. Therefore, by applying Bloom's taxonomy to critique course objectives or outcomes, the depth of learning can be measured. Figure 1 shows Bloom's taxonomy with the broadest levels of learning in each domain lying in the outer ring and with optimum learning occurring at the bull's eye. The validity of the hierarchical structure has been extensively analyzed since disagreement of the classification of objectives or outcomes

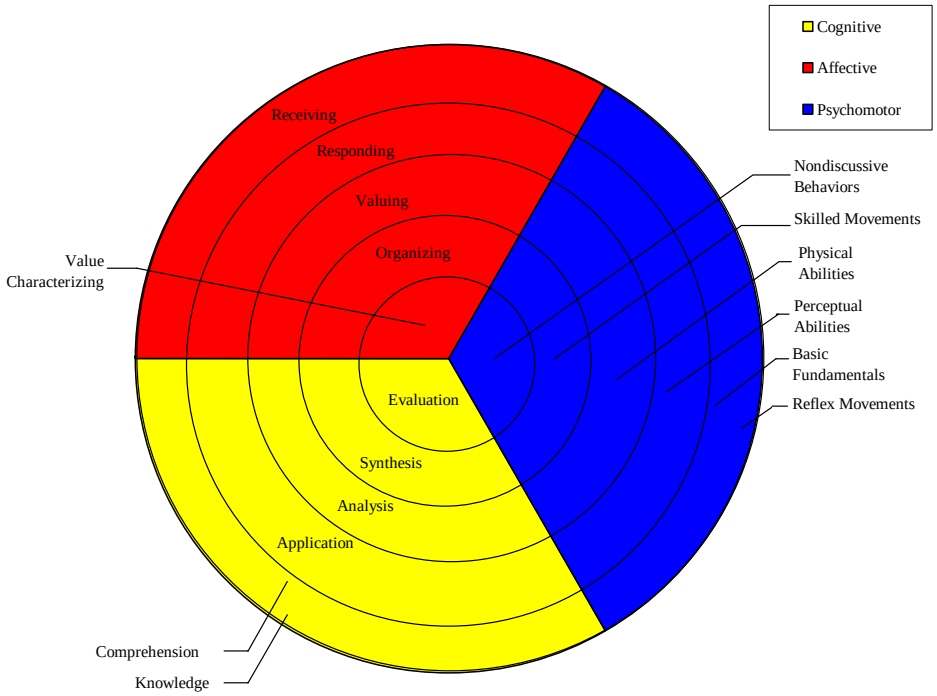

Figure 1: Integrating the three domains of Bloom's taxonomy to highlight optimum learning.

into the taxonomy levels occurs between judges[8]; to improve the validity of applying the taxonomy, the most complex levels of each domain can be grouped together. For example, the cognitive levels of analysis, synthesis, and evaluation are sometimes grouped together into a broader category labeled "higher-order" thinking[8].

Methods

The educational assessment plan for the 2004 EPSC course consisted of a variety of surveys and limited observations. The assessment implemented six specific tools, with the first five classified as surveys and the last deemed as observations:

- Direct paraphrasing activity,
- Teacher-designed feedback form,
- MTU Student Rating of Instruction instrument,
- ABET proposed syllabus and evaluation forms,
- Feedback form designed for the professor,
- Student course work, which includes comments from members of the Civil and Environmental Engineering Professional Advisory Committee (CEEPAC).

The direct paraphrasing and teacher-designed feedback surveys were created by the evaluator for mid-term and final course assessments. Out of fifty assessment techniques that passed a seven-question peer review (Appendix A)[22], seven were selected by the evaluator for a final comparison of their applicability to the EPSC course (Table 3). These two assessment techniques, direct paraphrasing and teacher-designed feedback forms, were chosen as course assessment tools because:

Table 3: Evaluation of classroom assessment techniques and their applicability to the EPSC course.

Classroom Assessment Technique	Empty Outlines (#4)	Muddiest Point (#7)	Approximate Analogies (#15)	Direct Paraphrasing (#23)	Student-Generated Test Questions[a] (#25)	Classroom Opinion Polls (#28)	Teacher-Designed Feedback Forms (#43)
Function Cluster	Assessing Prior Knowledge, Recall, Understanding	Assessing Prior Knowledge, Recall, Understanding	Assessing Skill in Synthesis and Critical Thinking	Assessing Skill in Application and Performance	Assessing Skill in Application and Performance	Assessing Students' Awareness of Their Attitudes and Values	Assessing Learner Reactions to Teachers and Teaching
Time Required for Tool Creation, Implementation, Analysis	Medium, Low, Medium	Low, Low, Low	Low, Low, Medium	Low, Medium, Medium	Medium, Medium to High, Medium to High	Low to Medium, Low, Low	Medium, Low, Low to Medium
Technique Description	Students fill in the blanks of an empty or partially completed outline of presentation/homework assignment provived by instructor.	Students jot down a quick response to: "What was the muddiest point in a lecture, a homework assignment, a play, or a film.	Students complete the second half of an analogy (A is to B as X is to Y), which instructor provided the first half.	Students paraphase part of a lesson for a specific audience and purpose, using their own words.	Students prepare test/*laboratory discussion* questions and model answers.	Students select the level of agreement/ disagreement with particular statements.	Students complete a short (3-7 questions), multiple choice or short answer survey.
Faculty Benefit	Discover how well students have "caught" the important points of a lecture, reading, etc.	Discover which points are most difficult for students to learn.	Discover how well students understand relations between two concepts.	Assess how well students have understood and internalized learning.	Determine concepts students feel are the most important and assess how well they can explain those concepts.	Discover students' opinions about course-related issues, which can help remove "roadblocks."	Determine ways to improve teaching methods
Students Benefit	Improves retention & understanding of material.	Require higher-order thinking to quickly identify muddy points.	Provides practice in making connections & extends "knowledge networks."	Provides practice summarizing concepts for audience outside classroom.	Assess how well they know the material and results help them refocus learning.	Discover own opinions about issues and compare opinions with classmates or experts.	Provide detailed feedback early enough to benefit from its use.
Ideal Situation	Course with large amount of content (facts & principles) presented regulary in highly structured manner	Large, lower-division classes	---	Courses with concepts that students will later be expected to explain to others	Courses in which student take tests (*or write lab reports*)	Courses with controversial issues	---
Reasons Not to Apply Technique to Laboratory Assessment	Facts & principles are not presented in highly structured manner	Not a lower division class	Time consuming to create assessment tool	---	Students in process/previously composed laboratory reports	Course already in session; therefore, cannot poll students before learning starts	---

[a]Student-Generated Test Questions Technique can be modified to Student-Generated Laboratory Discussion Questions to be more applicable to course.

- The function of the direct paraphrasing technique was to evaluate students' skills in application and performance while the function of the teacher-designed feedback form was to evaluate students' reactions to the teacher and the teaching[22]. The direct paraphrasing activity fit well into the hands-on course since students learn concepts about water and wastewater treatment design and operation that they will likely have to explain to and/or discuss with others in future careers; this technique gives the students a chance to practice paraphrasing what they learn while allowing the instructor to assess how well the students have understood the material.
- Both quantitative and qualitative data about the students' learning experience could be collected.
- The time commitment for the evaluator was not ranked as extensive. The time required for the customized feedback form was rated as medium, low, and low to medium with regards to tool creation, implementation, and analysis, respectively, while the time required for the direct paraphrasing activity was classified as low for the creation stage and medium for both the implementation and analysis stages.

These two types of surveys were created based on literature examples; the surveys were then reviewed by two colleagues. The direct paraphrasing tool consisted of two scenarios; within a three-minute time limit, students were required to explain a given aspect of a treatment technique to a targeted audience for each scenario. The direct paraphrasing exercise was skipped during the final course assessment to avoid overwhelming the students since they were also required to complete the MTU standard course assessment form. The majority of questions on the teacher-designed feedback form required students to self-assess their level of comfort working with a given process. The mid-term and final versions of this feedback forms varied slightly; however, both forms asked students to identify unclear components (i.e., muddiest points) of the laboratory experiments. An evaluation rubric was drafted for the final evaluation form; the goal of a rubric is to inform the participants clearly and honestly why the data is being collected and how it will be utilized[7].

The MTU Student Rating of Instruction Instrument was the next tool utilized in the course critique; this standard form is completed by students for each of their courses at the end of a semester. The campus-wide form, which was created by MTU's Center for Teaching, Learning, and Faculty Development[23], contains twenty statements to which students indicate the level to which they agree with the statements; a ranking system from one to five is utilized with one standing for "strongly disagree" and five representing "strongly agree". Eighteen out of the twenty statements are "…intended to be formative in nature and are based on contemporary 'best practice' models derived from higher education research and reflection" while the aim of the remaining two statements is to "…elicit responses from students as to their overall assessment of the instruction[24]." This survey also provides students with an opportunity to state the aspects of the course the teacher should retain and those aspects he/she should change for the proceeding course.

The students' course work, which includes team laboratory reports and posters for the spring 2004 session, was collected to be analyzed in order to assess students' understanding of key course concepts. Unfortunately, a pre-test activity was not conducted at the beginning of the semester; therefore, the knowledge gained by the students as a result of the EPSC course could

not be measured. The posters created by the students were presented to CEEPAC members at the end of the semester; the members of CEEPAC were then asked to give their impressions of the course from an industry perspective based on their limited exposure. The importance of this tool was to provide evidence that either supported or contradicted the need for the undergraduate hands-on course focusing on treatment systems.

Additionally, the level to which the course met its proposed objectives and ABET outcomes was evaluated by comparing the proposed syllabus to the ABET Reflective Course Assessment form. On the end-of-semester form, the most and least successful components of the EPSC course were identified along with ideas to improve the course for the spring 2005 term. The proposed syllabus was composed by the professor while the evaluation form was completed by the professor and the evaluator.

The final tool utilized for the 2004 EPSC course assessment was the survey completed by the professor at the end of the semester. This evaluation form was created by the evaluator and provided the professor with an opportunity to list course components that he would like to change and those he would like to retain for the next year. This tool was compared to the results of the student evaluation forms and trends between successful and unsuccessful course aspects for the students' and professor's perspectives were recognized.

Based on the lessons learned from the 2004 course, the assessment plan for the following year was modified. The assessment plan for the 2005 course integrated the guidelines outlined in ABET's Criterion 3 with Bloom's taxonomy. To create the 2005 assessment tools, the target outcomes of the course were first identified. Next, the level of Bloom's Taxonomy in which the outcome had the potential to reach was determined, followed by identifying the opportunities provided by the course to expose students to the target outcomes. The final step in the planning stage was to create an indicator to measure each target outcome. For the educational assessment of the 2005 course, six tools were utilized with the first classified as a combination of a survey and baseline data, the next three considered surveys, and the remaining labeled as observations:

- Teacher-designed feedback form,
- MTU Student Rating of Instruction instrument,
- ABET proposed syllabus and evaluation forms,
- Feedback form designed for the professor,
- Student course work,
- Observations.

The teacher-designed feedback form created for the 2005 course varied significantly from the form for the prior year. Bloom's taxonomy was used to guide this assessment tool, which resulted in questions covering all three domains of cognitive, affective, and psychomotor. The survey was divided into the following six sections: (1) self-assessment of skill rating, (2) key vocabulary matching, (3) unit process schematic illustrations, (4) a variety of questions focusing on the affective domain, (5) standardized questions extracted from the Fundamentals of Engineering Exam review material, and (6) scenarios requiring students to incorporate different issues into design decisions. By applying the theory of Bloom's taxonomy to craft this assessment tool, the depth of learning in the three categories can be more readily measured. The survey was given to the students as a test at the start of the course; the same questions will be

completed by the students at the end of the course with the addition of requiring students to identify the muddiest points of each laboratory experiment every two weeks and to complete weekly safety checklists. Since this tool collects data before and after an intervention, it is an example of a baseline data study.

In addition to the observations of the students' course work, which includes team laboratory reports, posters, and the Chemical Hygiene and Safety Quiz, observations are recorded during each period. These observations provide the direct measurements of student learning, which was lacking in the 2004 assessment. In order to eliminate collecting unnecessary data, an observation protocol, which focused observations on laboratory safety, teamwork, student skill using instruments, and problems encountered, was composed.

The two assessment plans were analyzed and compared using Bloom's taxonomy as the criteria. For each assessment tool, the question of "what level of student learning can this tool measure?" was answered. The results were plotted on a bull's eye graph allowing for easy visual comparison. The validity of each assessment was determined by comparing the levels of Bloom's taxonomy covered by the course objectives and those measured by the assessment tools.

Results and Discussion

Before the assessment plans for the EPSC course were compared, the objectives of the course were critiqued using Bloom's Taxonomy. The course objectives were listed on the syllabi provided to the students as the same for both years; however, before the start of the 2005 course, more specific target outcomes were compiled. After completing the EPSC course, students should be:

- Able to put theory into practice.
- Knowledgeable of laboratory safety procedures and committed to practicing laboratory safety.
- *Familiar* with laboratory equipment (e.g., pumps, columns, etc.) and be *comfortable* operating and performing basic maintenance on them.
- *Comfortable* creating solutions and performing analytical techniques.
- Able to gather data in a *proper* way.
- Able to draw schematics of each unit process.
- *Comfortable* operating each unit process.
- Knowledgeable of the physical, chemical, and biological processes related to each treatment system.
- Able to perform design calculations for each unit process.
- Able to apply data obtained from the laboratory setting to design of treatment processes.
- Able to write *good* reports.
- Able to work *well* with others.

The italicized words listed in the target outcomes are considered vague and were further defined to more clearly indicate the expectations for the students.

Figure 2 illustrates the levels of Bloom's Taxonomy covered by the course objectives as listed in the syllabus (labeled as 2004 goals) along with the more specific target outcomes (labeled as 2005 goals). The majority of the course objectives focus on the lower levels of the cognitive

domain with one objective hitting the evaluation level of that domain and two objectives falling in an upper level of the psychomotor domain. Comparing the target outcomes to the objectives, the outcomes cover a wider range on the taxonomy with an outcome hitting the most sophisticated level in each of the domains; the majority of the outcomes, however, still lie within the lower levels of the cognitive domain. Course goals focusing on the lower levels of Bloom's taxonomy is a common finding when the goals and learning are critiqued using this framework[14,17,18].

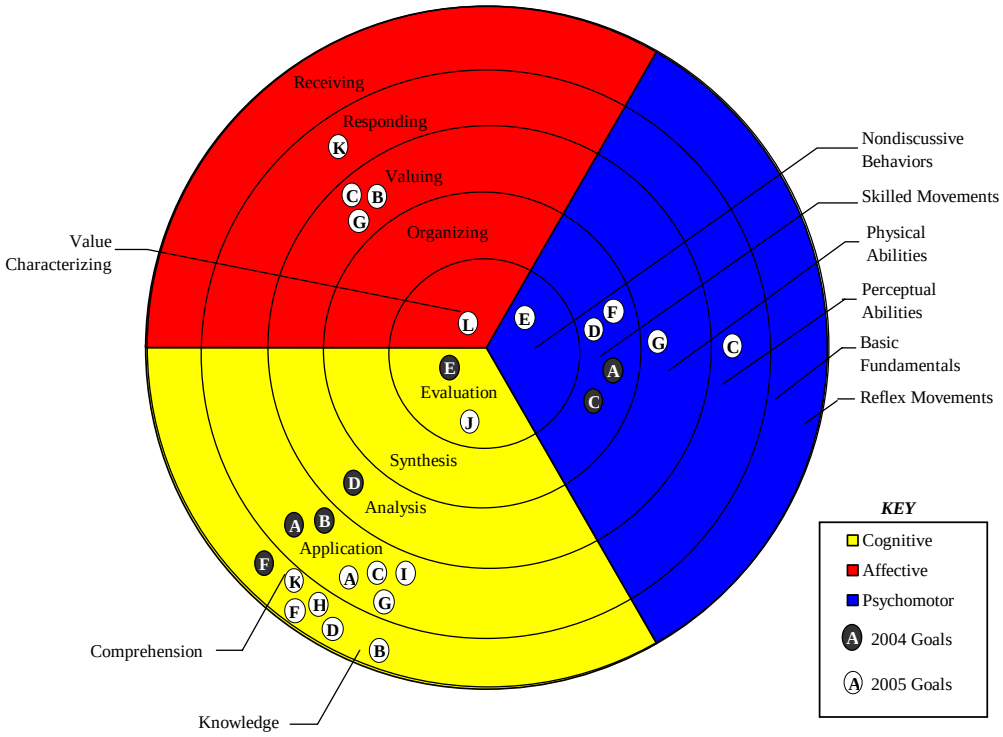

Figure 2: The abilities of course objectives to cover levels of learning of Bloom's Taxonomy.

The effectiveness of the assessment plans was examined using the taxonomy as demonstrated in Figure 3 with the highest taxonomy level that can potentially be examined by a specified tool shown. The assessment plan for spring 2004 had the potential to measure up to the analysis stage of the cognitive domain and up to the organizing level of the affective domain; this assessment lacked the capability to measure the degree of student learning in the psychomotor domain. On the other hand, the spring 2005 assessment plan could potentially measure the most sophisticated level of learning in each of three domains.

By comparing Figures 2 and 3, the validity of each assessment can be determined. The 2004 assessment plan appears to be misaligned with the course objectives; this plan focuses on the lower levels of the cognitive domain along with providing measurements in a lower and higher level of the affective domain while the course objectives focuses on the lower levels of the cognitive domain along with targeting the highest level of that domain and higher levels of the psychomotor domain. The 2005 assessment plan is still not completely aligned with the course objectives as seen by the plan covering the affective domain even though no objectives lie within

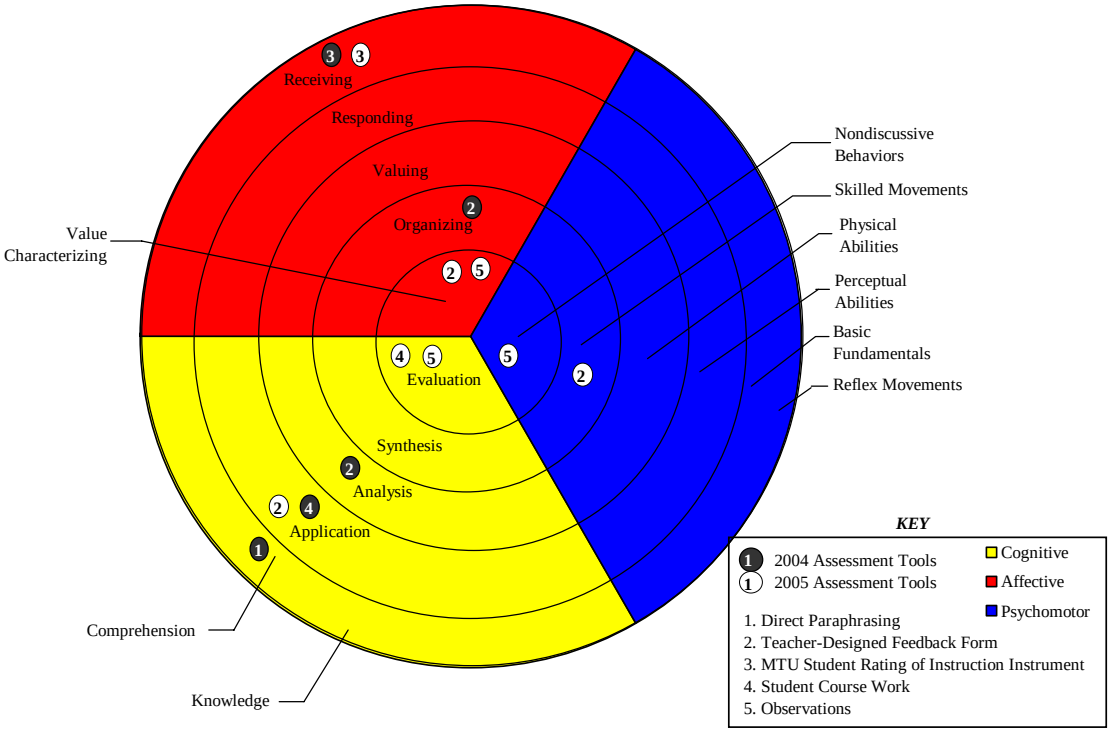

Figure 3: A comparison of the 2004 and 2005 EPSC course assessment plans.

that domain. However, this assessment plan is more thoroughly aligned with the target outcomes for the 2005 course as the plan has the potential to measure student learning at the bull's eye, or optimum level, of the taxonomy. The 2005 assessment plan appears to be more valid than the 2004 plan, but further work is needed to clarify the course objectives and communicate them to the students and to refine the alignment of the assessment plan and the objectives.

Even though tools from multiple stakeholders were implemented for the education assessment of the 2004 EPSC course, there are weaknesses that need to be addressed to improve future EPSC course critiques; these weaknesses include:

- Failing to close the feedback loop by not providing students with the assessment results during the ongoing of the class. This error is due to lack of planning since the time commitment for the assessment was limited and the structure for the assessment was not set up prior to the start of the course.
- The biases of the evaluator, the course professor, and the students. Student biases may include responses or observations which do not reflect "true" behavior, characteristics or attitudes, which may be caused by unclear assessment questions, by respondents intentional equivocate, or by changing of student behavior due to observations[7].
- The inability to fully compare the students' performance before and after course in designing and operating treatment systems. Two reasons can account for this weakness; first, vague terms and measurements were included in the evaluator-designed forms and second, a pre-test was not given to the students on the first day of the course in order to assess the level of design and operation skills the students possess at the start of the course. The changing of question wording was kept to a minimal between the midterm

and final teacher-designed feedback forms to prevent decreasing the validity of the time comparison[7].

- The over-reliance on surveys, as they provide only participants' opinions on how much they have learned as well as opinions on other subjects that may not directly relate to learning[9].

Based on the critique of the 2005 assessment, strengths and weaknesses of the plan can be predicted. Potential strengths of the 2005 assessment plan include: (1) incorporating tools that measure both direct and indirect student progress, (2) collecting data at the start and end of the course, which allows for the change in student learning resulting almost exclusively from the course to be measured, and (3) exposing students to important concepts during the pre-test activity at the start of the course. The potential weaknesses of the plan include: (1) missing important observations, (2) lacking an incentive to motivate students to perform well on the assessment tests, which is thought as a weakness of standardized tests since grades are not given[8], (3) misinterpretation of Bloom's taxonomy, which Bloom himself acknowledges that the categories cited in his work could not be defined clearly and were open to some interpretation (Bloom et al. 1956)[20], and (4) the biases of the evaluator, the course professor, and the students, as described above.

In order to determine if the EPSC course is actually bridging the gap between school and the workplace for environmental engineering graduates, three pieces of evidence from different perspectives are presented. From the students' view, the course increased their confidence in designing water and wastewater treatment systems, as shown in Figure 4; it should be noted that the response rate for the midterm and final surveys varied, with 100% and 69% of the students responding, respectively. Table 4 explains how the EPSC course contributed to meeting the ABET program outcomes; the opinions expressed in this table are those of the professor and the evaluator. From an industry perspective, a member of CEEPAC felt "the tests that were completed and presented [were] very representative of what students may encounter in industry" while another member commented that "…in discussion with students it appears that…the lab brought theory to life." Based on these different viewpoints, one can conclude that the EPSC course has the potential to enhance students' transitions into industry. By collecting direct measurements of student learning in the 2005 course, the ability of the course to reduce this gap can be more thoroughly assessed.

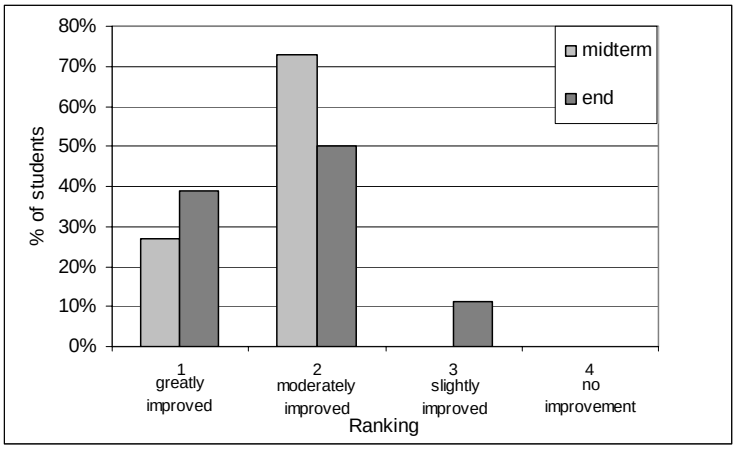

Figure 4: Level of confidence designing treatment systems gained from the 2004 EPSC course.

Table 4: The contribution of the 2004 EPSC course to ABET program outcomes.

ABET Program Outcomes	Significant Contribution Activites
Apply knowledge of mathematics, science, and engineering	Most all the assigned laboratories exercises the students perform deal with applying mass, energy, momentum balances for development of individual process design equations and require the application of math, science, and engineering. [2]
Ability to design and conduct experiments, as well as analyze and interpret data	Operate several bench-top and pilot-plant unit operations, measure, analyze & interpret the process performance data. [2]
Ability to design a system, component, or process to meet desired needs	Apply the bench-scale and pilot-plant results to the design of a full scale system. [2]
Ability to function on multi-disciplinary teams	Students work in teams, but not multidisciplinary. [1]
Identify, formulate, and solve engineering problems	Formulate the experimental protocol for each unit operation and Apply engineering procedure and modeling methods to the above unit processes as stand alone or in combination to identify and solve operational problems. [2]
Ability to communicate effectively	Students are given an oral exam before operating each unit process. Students work in teams to write the laboratory reports for each unit operation. Students also demonstrate the operation of each unit process to the following group. Students also present posters on a given unit process. [2]
Knowledge of contemporary issues	The process control system and pilot plant unit operations used by the students are "state of the art" and used by practicing engineers in today's industry. [2]
Ability to use the techniques, skills, and modern engineering tools necessary for engineering practice	MathCAD and spreadsheets were used in several of the exercises to solve engineering design calculations. [2]

Numbers in brackets [ ] indicate level of outcome coverage on a scale from 0 (none) - 2 (Significant Coverage).

Not included in proposed Spring 2004 ABET course syllabus.

Conclusions

Bloom's Taxonomy provides a useful framework for examining course objectives along with assessing student learning. The 2005 assessment plan appears to be more valid than the 2004 plan, but further work is needed to clarify the course objectives and to refine the alignment of the assessment plan and the objectives. The incorporation of both direct and indirect measures into the current plan should allow for a more accurate evaluation of student learning. The assessment process should be further incorporated into the daily classroom work to enhance students' learning experiences[7] and to allow the engineering design faculty to demonstrate through their own actions the very principles of their subject matter (i.e., engineering design)[25].

The 2004 course proved to be a success by providing students with valuable hands-on design, operation, and analysis experience of treatment systems; however, many areas for improvement were identified. Based on the 2005 findings, EPSC course and assessment plan should be further refined for the next course offered to enhance the learning experiences of the students.

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Biography

DAVID W. HAND has been a professor in the CEE Dept. at MTU since 1996. Since 1983, he has been a principal or co-principal investigator in funded projects (over 8.0 million dollars) in environmental engineering research, focusing on physical & chemical processes. Dr. Hand has published over 80 peer reviewed publications in 7 different journals, contributed/coauthored 3 text books, co-recipient of 2 patents, & 8 copyrighted software programs.

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Appendix A
The Seven Question Review Applied to 50 Classroom Assessment Techniques[7].

Classroom Assessment Technique Review
Is it context-sensitive? Will the assessment technique provide useful information on what a specific group of students is or is not learning about a clearly defined topic at a given moment in a particular classroom?
Is it flexible? Can faculty from a range of disciplines easily adapt the technique for use in a variety of courses and contexts?
Is it likely to make a difference? Does the technique focus on "alterable variables"? In other words, does it assess aspects of teaching or student behavior that could be changed to promote better learning within the limits of time and energy available in a semester?
Is it mutually beneficial? Will it give both teachers and students the kind of information they need to make mid-course changes and corrections in order to improve teaching and learning?
Is it easy to administer? Is the assessment technique relatively simply and quick to prepare and use?
Is it easy to respond to? Is the feedback that results from the use of the technology relatively easy to organize and analyze?
Is it educationally valid? Does it reinforce and enhance learning of the specific content or skills being assessed?