2006-1105: BUILDING A BETTER HYBRID: ENVIRONMENTAL MONITORING AND MEASUREMENT ANALYSIS

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Building a Better Hybrid: Environmental Monitoring and Measurement Analysis

Motivation

For most students, learning in context improves retention through improved motivation and connection to other knowledge. In an effort to elevate retention of data analysis methods, a hybrid class that integrates environmental issues, analytical methods, and statistical analyses was designed for the sophomore year of the undergraduate environmental engineering program at Michigan Technological University (Michigan Tech). This paper details the course objectives and design, the educational models influencing its form, and some preliminary outcomes.

Learning Preferences

There are several methods to assess learning preferences[1]. One method applicable to science and engineering students is the Index of Learning Styles[2]. This forty-four question assessment is easily administered via a web-based questionnaire[3]. In this method learning preferences are determined with results along a spectrum of four learning pairings: sensing-intuitive, global-sequential, active-reflective, and verbal-visual. No two students learn exactly alike. Learning style is simply a preferred way of learning – often the way(s) that knowledge "sticks" most easily. While the diversity of learning styles can be a source of frustration for educators, it can also be used as insight on how to design a course that more effectively educates most of the students.

Analysis of the learning preferences for environmental engineering students at Michigan Tech reveals the problem with most courses: they are designed in a manner incongruent to the natural learning preferences of most students. Figure 1 shows the results of this study. Responses from two different years are presented and reveal relative similarity in the classes' mosaics of learning styles.

The results from the active-reflective pairing indicate a good balance among the students; some active and some reflective activities would be a good mix. Active learners like to do something with new knowledge, discussing or applying it are both useful in this regard. Reflective students like to quietly think about new knowledge before doing something with it. As might be expected, active learners prefer to work in groups, but reflective students prefer working alone.

Examining the sensing-intuitive pairing it is found that a majority of the students have a sensing preference (instead of an intuitive learning preference). Sensing students like to have facts and observations to comprehend their world. Intuitive students are comfortable reaching that point on hunches and possibilities. Sensors like solving problems by established methods, intuitors like innovation and dislike repetition. Sensors are generally better at memorizing facts and being tested on such material, whereas intuitors are better at abstractions. Lastly, sensing students prefer material with real world connections, yet intuitive students tend to not like such applied classes.

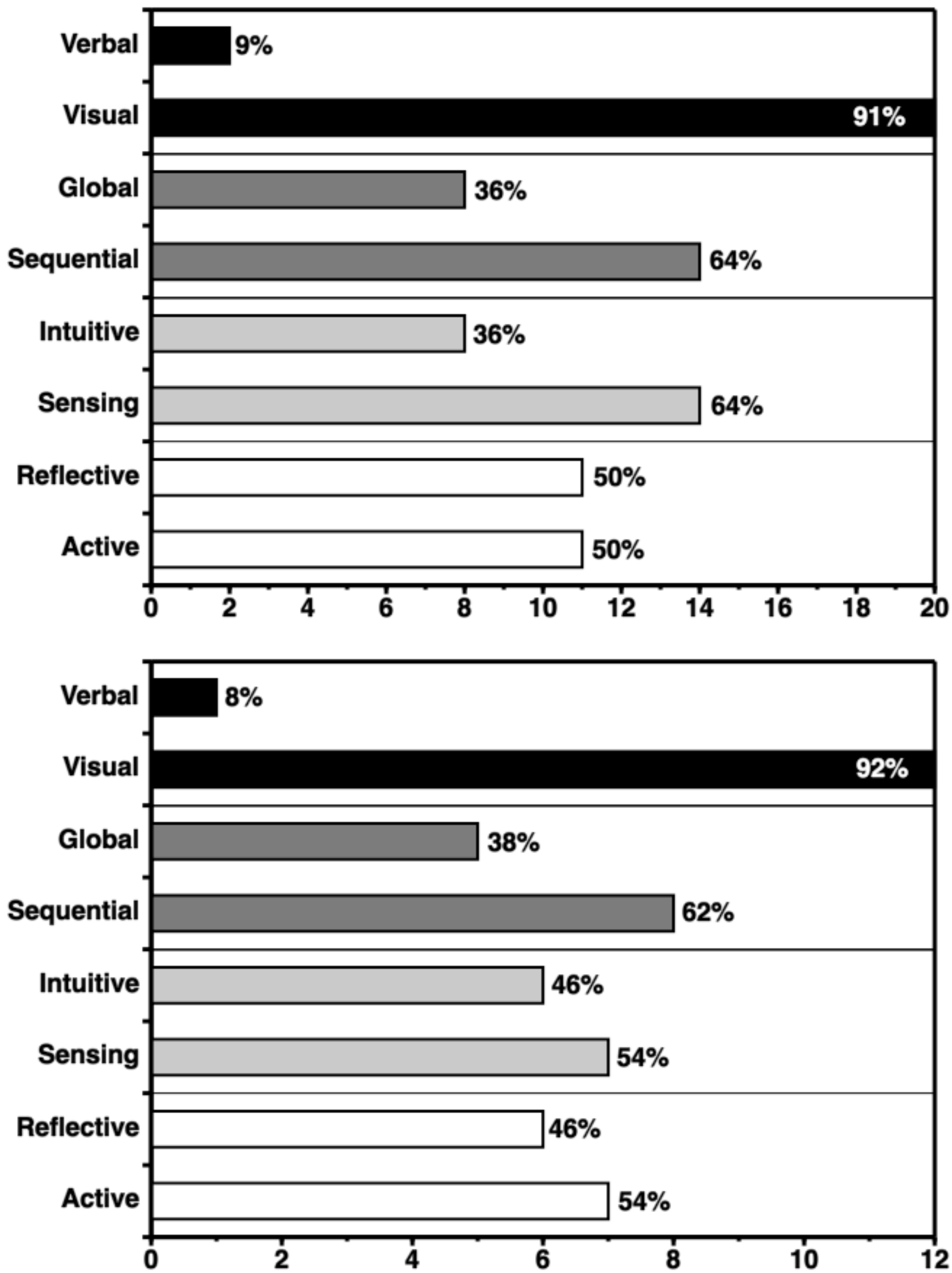

Figure 1. Index of Learning Styles results for two classes of environmental engineering students at Michigan Tech in 2005 (top) and 2006 (bottom) (n=22 in 2005, n=13 in 2006)

The sequential-global comparison shows that almost two-thirds of the students prefer learning sequentially. In such learning, the structure of the course flows logically from one topic to the next. For these students, the big picture is revealed at the end, after all the parts are assembled. Global learning on the other hand can begin with the big picture and amass the parts in apparently random manner upon which the whole makes sense. Sequential learners solve problems in a step-by-step manner, whereas global learners may solve complex problems quickly but have difficulty identifying the process they went through.

The last pairing produced by the ILS is the verbal-visual. Nearly all students have a visual preference. Visual students learn best by what they see (photographs, schematics, movies, animations, etc.). Verbal learners learn more by what they read or hear.

The results above are similar to the learning preferences of a few hundred undergraduate students[4]. The evidence highlights the mismatch of the typical class structure – the lecture (an intuitive, sequential, reflective, verbal teaching method) – and the typical student (sensing, sequential, active, visual). While the goal of a well-designed class is not to pander to the students' preferences all the time (after all, each student is a different mix of the above four pairings, and does have the ability to learn via their weak traits), this evidence hints at potential strategies that could be used to elevate learning for the entire group. The course described herein utilizes such strategies.

Long-Term Retention of Material

The "evaporation" of knowledge is a common frustration among teachers and professors. Material is covered one semester only to largely disappear by the next. Studies have shown that in a typical class, only 10% of the material is retained three months after the end of the course[5]. The problem is the above-mentioned mismatch between students' learning styles and educators' teaching approaches. A key goal of the course described below is greater retention of the material by the students. This will be achieved by using a combination of teaching methods in order to connect with the diversity of learning styles within any group of students. Direction is provided by retention research by Dale that is modified and presented in Figure 2 below[6].

The course utilizes many of the strategies along the path in Figure 2. Although lecture has a notoriously low retention rate, it is primarily due to the length of lecture; lecture is still effective at conveying basic information, particularly from an expert viewpoint. Lecture is not abandoned in the learning modules that compose this class; rather it is used as one (short) component of an effective whole. Students, though, will be frequently led to higher levels of the learning path shown in Figure 2. The next section reveals how.

Course Structure

Based on the learning principles presented above, a typical college class is an inadequate model for the course. Instead, the course, *Environmental Monitoring and Measurement Analysis (EMMA)*, was built upon a nested modular framework. Each module is one week in duration. The modular approach allows future instructors great flexibility in assembling the most topically appropriate course. Since knowledge retention is a major goal of the course, the class structure needs to assist rather than detract from methods used. Kolb identified a cyclic structure that elevates retention among students[7,8,9]. Using Kolb's four-step cycle (Motivation, Theory, Application, Analysis) as a core, every module is built upon a Learning Spiral, which has six basic components:

1. Motivation
2. Theory
3. Application
4. Analysis
5. Assessment
6. Self-Directed Learning

This Learning Spiral educational framework is depicted in Figure 3 below.

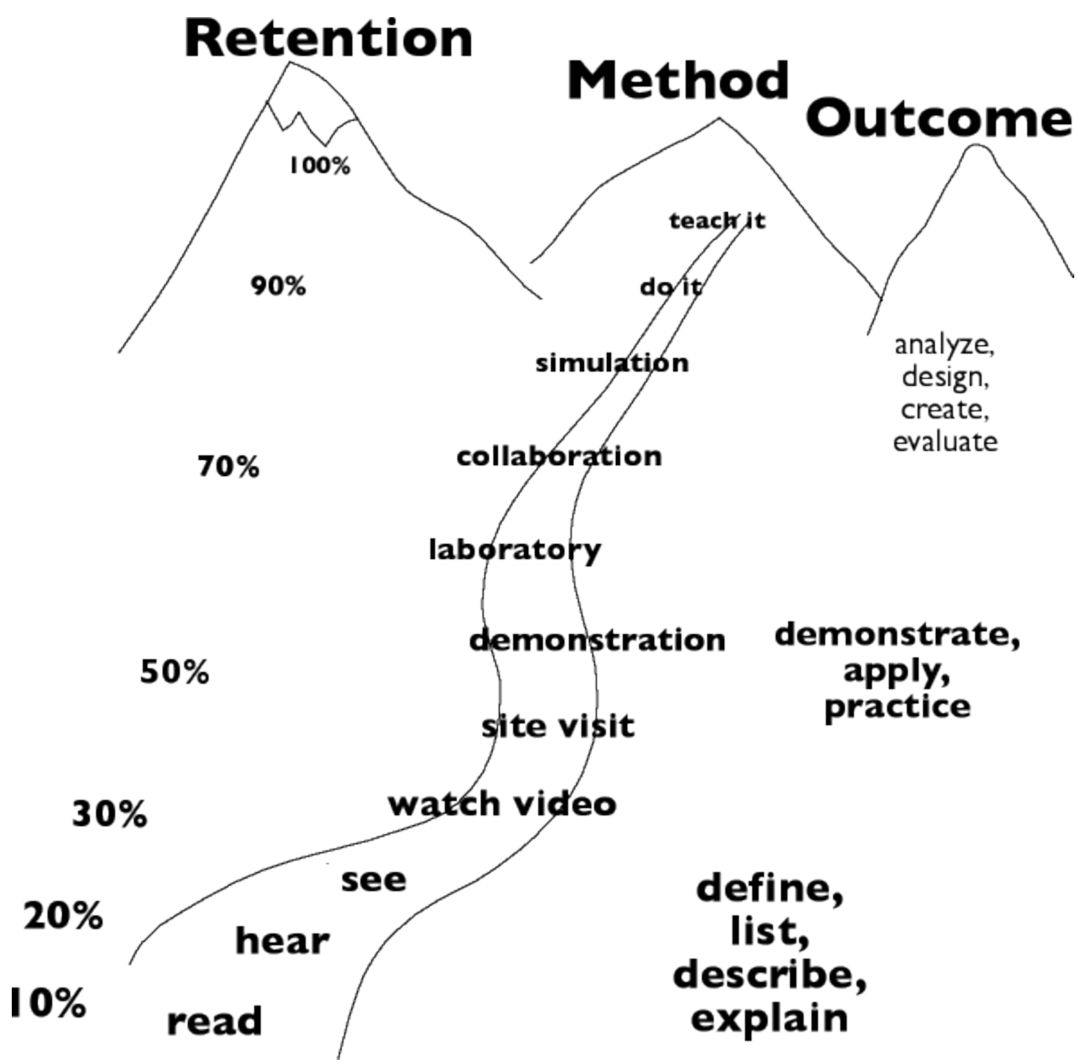

Figure 2. The three pinnacles of learning: retention, method, and outcome. The level of teaching method used is related to the retention of material and the types of outcomes that students are able to perform. Adapted from Dale[6].

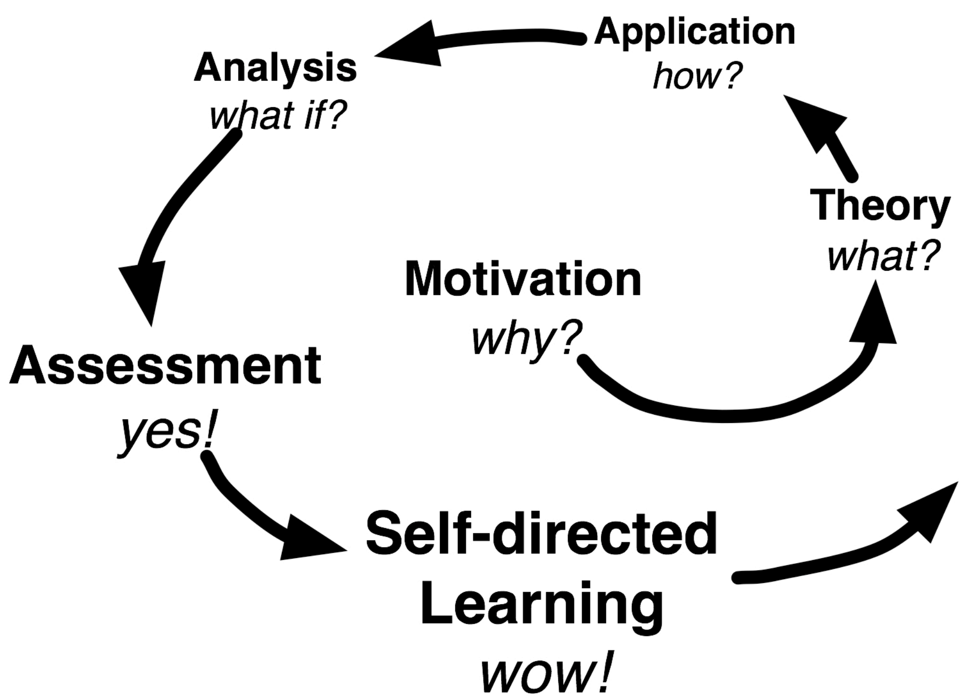

Figure 3. The Paterson Learning Spiral depicts the general path of every module in the *Environmental Monitoring and Measurement Analysis* course.

EMMA is organized in one-week long Learning Spirals each focusing on different statistical and analytical techniques, as well as environmental issues: lectures present statistical theory, laboratory and field sessions provide opportunities to acquire data, out-of-class teamwork sessions are used to analyze the data, presentations of findings allows time to discuss the material, a quiz is used to check mastery of the topics, and resources are provided for advanced study. The Learning Spiral proceeds as follows through the week:

1. **Wednesdays**, Statistical Theory (*Motivation and Theory*)
2. **Thursdays**, Monitoring and Data Collection (*Application*)
3. **Fridays-Sundays**, Data Analysis (*Analysis*)
4. **Mondays**, Oral Presentations, Discussion, Quizzes (*Assessment*)
5. **Wednesdays**, Written Reports (*Self-Directed Learning*)

While Kolb argues that structuring education along his four-step cycle allows a student to begin learning at any of the four steps, the modules developed for this course all begin with Motivation as a natural starting point. As many students are sequential learners, they appreciate the consistent pattern. The module Motivation establishes the reason for wanting to know about the topic, its importance, its *Why?* This is promoted through a diversity of approaches from shocking factoid to riveting case study to class debate. Once the Motivation is evident for most students, learning will flow. The next stage of the modules is the Theory. This is the only portion of the module that may resemble a lecture (and a short one at that). This is where the science, methodology, and evidence are revealed. It's the *What?* of the module. This often requires a combination of equations, schematics, photographs, tables, graphs, and text. The motivation and theory are primarily delivered during the one traditional class of the week, on Wednesdays. The nested module structure begins here (Figure 4) and the course instructor takes center stage. Wednesdays are used as the start of the weekly Learning Spiral. These sessions, a hybrid of lecture, problem-based learning, and discussion section are when the statistical theory for the week (see Table 1) is presented. Each week focuses on one statistical topic (or related set of topics). Within these Wednesday classes, the statistical material follows a one-day Learning Spiral of its own. Motivation for learning the statistical technique is produced in some of the ways mentioned above. No more than five minutes of class time is used for this stage. The theory (definitions, mathematics, resources) is covered next, taking twenty minutes or so. Then over a ten-minute period the students engage in an application of the theory via problem-based learning. Students are engaged in analysis by discussing possible solutions to one or more open-ended questions (five to ten minutes). Several show-of-hands multiple-choice questions allow the instructor to assess comprehension (three to five minutes). Lastly, a list of web-based resources for advanced learning is provided at the end of each Wednesday class.

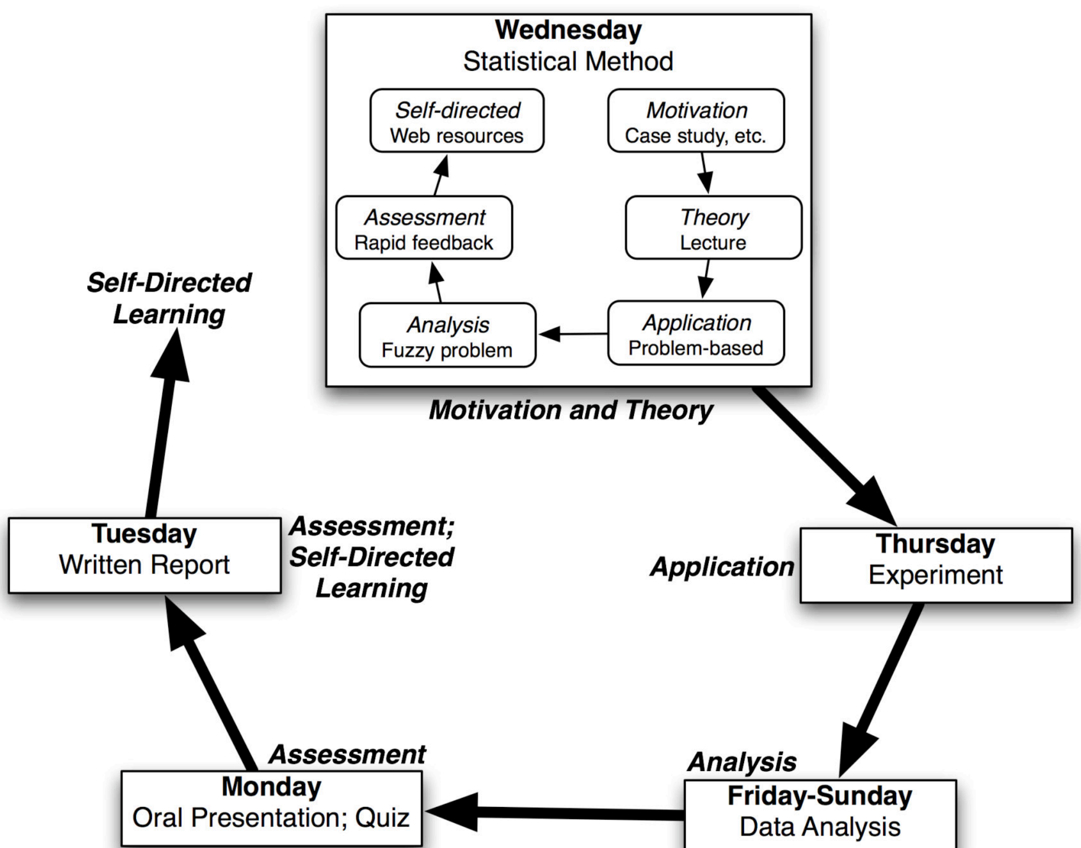

Figure 4. The nested Learning Spiral course structure. A one-day spiral, on Wednesday, is nested within the one-week long course module spiral.

Table 1. Statistical topics covered in *Environmental Monitoring and Measurement Analysis*

Week	Statistical Topic
2	Bias, precision, accuracy
3	Plotting data, correlation coefficients, least squares
4	Smoothing data
5	Distributions and normality
6	Confidence intervals and percentiles
7	Limit of detection
8	Assessing conformance with a standard
9	Assessing differences
10	Analysis of variance
11	Error propagation
12	Assessment of outliers
13-14	Group research project
Final	EMMA Fest

After the one-day Learning Spiral for the statistical technique is concluded, the one-week long module (statistics, analytical methods, environmental issue) is ready for the third phase in its Learning Spiral. This third phase, Application, takes place in the laboratory (or field). In this phase, the students are asked to put the Theory to use. By doing so, students will better understand *How?* An effective strategy to use in this phase is problem-based learning. Laboratories serve this role well. Students work on the laboratories in groups of 3-4 to elevate mastery through cooperative learning where the students are essentially teaching each other. Typical laboratory topics are presented in Table 2. The laboratory experiences are designed with the data analysis technique in mind. Datasets appropriate for application of the companion statistical topic must be collected, for example. Each laboratory handout has sections on the environmental significance of the subject, a description of the laboratory procedure, and several questions to guide the students through the analysis of their data with the statistical method for the week.

The Analysis step is the fourth element in the Learning Spiral. This is the time to have the students think of potential complications, implications, connections, and issues by asking *What if?* A simple way to facilitate this is to pose a problem similar to that in the Application section but with one variable or condition changed. These variable conditions are built into the laboratories; each lab section has slightly different operating or initial conditions. As one group from each lab section presents their findings orally on Mondays, the influence of such conditions are revealed in the evidence presented, providing a rich opportunity for deeper understanding of the analytical and environmental materials.

Table 2. Laboratory topics (environmental and analytical) covered in *Environmental Monitoring and Measurement Analysis*

Week	Environmental Topic	Analytical Topic
2	Solids in water	Solids filtration
3	Sequencing batch reactors	BOD, COD tests
4	Reactor tracer study	Spectrophotometer
5	Indoor air pollution	Carbon dioxide and particle concentration monitors
6	Air particle size monitoring	Particle size distribution monitor
7	Snowpack pollution	Chloride probe
8	Chloroform in tap water	Gas chromatograph
9	Lake dissolved oxygen	Dissolved oxygen probe
10	Solid waste analysis	Waste separation, mass and volume estimation
11	WWTP process stream analysis	Flow, total dissolved solids, temperature, pH field sensors
12	Reactor operation and design	Calcium and ammonium computer-controlled probes
13-14	Group research project	Project dependent

The Assessment is a critical diagnostic of success and is the fifth step in the Learning Spiral. The Assessment can be administered in a couple minutes and focuses on a few short questions based on the material in the module (statistical, analytical, and environmental). The ten-question multiple-choice quizzes are given to each student to fill out alone; then the students immediately re-take the quiz in their laboratory group. The latter step leverages the deep learning associated with explaining and teaching others (refer to Figure 2). The Assessment provides immediate feedback to the students and the instructor. The students can reflect on what might be challenging concepts and the instructor on what concepts might need to be addressed differently or again. Student groups average a 30% improvement in quiz score versus the individual effort. This activity is filled with intra-group discussion on which answer is correct and why. Student groups not presenting orally, can internalize this assessment to make final changes to their written reports that are due by the beginning of class on Wednesday, when a new week-long module begins. The written reports provide a self-directed opportunity to more deeply analyze the data and its connection to the environmental topic of the week. Depending on holidays, there are 11-12 one-week modules over the semester. Oral presentations are assessed via the instructor using a twelve-point grading rubric (Table 3), and by the other students in the class via discussion of strong and weak points following each presentation. This approach results in very rapid improvement in oral presentations. Written reports are assessed using a nine-point grading rubric (Table 4).

A major limitation of all courses is that time is finite. Decisions to restrict the material coverage are never easy, but if done correctly should provide a motivation for additional learning by the students. This sixth and final phase of the Learning Spiral, Self-Directed

Learning, provides a springboard for continued learning by offering several potential next steps for interested students. These online resources allow students to proceed as deeply into additional material as desired. This section simply gets a cursory note during the class, maybe 30 seconds. Students are directed to the learning resources for further information.

Table 3. Oral presentations assessment criteria using a scale of 1 (poor) to 5 (excellent) for each. Scoresheets are completed during the laboratory presentations by the instructor and given to student groups at the end of the class period. 60 points possible.

Content Criteria	
1.	Introduction motivates interest in work
2.	Clearly-stated objectives
3.	Methods and theory strongly support project
4.	Results and conclusions are clearly presented
5.	The presentation is effectively structured
6.	Overall effectiveness of communication
Delivery Criteria	
7.	Ability to explain
8.	Mannerism and eye contact
9.	Pace and length of presentation
10.	Professional appearance
11.	Effectiveness of visual aids
Question and Answer Criteria	
12.	Convincing answers to questions

Table 4. Written report assessment criteria. Score sheets are completed within a week of report submission. 100 points possible.

Criteria	**Possible points**
Cover page: Present and complete	5
Introduction: Background, summary of report, statement of problem	10
Methods: Complete (materials and equipment), general theory behind methodology	10
Results: Understanding of general trends and patterns, summary of data, appropriate and complete tables and graphs (title, number, legend, units)	25
Discussion: Appropriate interpretation of data, connection between data and existing knowledge, explanation of logic, suggestions for future improvement and/or research, major conclusions	20
References: Appropriate and complete, correct format	5
Appendices: Sample calculations, data	5
Writing Style: Professional tone, grammatically correct, clear, coherent, and concise	10
Presentation: Overall appearance, appropriate use of verbal and visual materials	10

The last three weeks of the semester are devoted to the execution of student-designed research projects. Student teams are required to plan, execute, analyze, and communicate their work, using as many statistical techniques as appropriate. The groups meet with the instructor near mid-term to discuss their initial concepts and strategies then spend the next month refining those plans. This may be the greatest opportunity for the sixth step of the Learning Spiral, Self-Directed Learning. Students are largely given creative control. The wealth of topics covered is impressive, the work even more so. The student projects are presented in a public symposium held in the evening during the last week of class, EMMA Fest. The project and class requirements conclude with the preparation and display of research posters throughout the department's hallways during finals week.

Conclusions

The long-term benefits of this class are clearly evident through senior exit interviews given to all graduating environmental engineering students over the past several years. While statistical and analytical methods are acquired by all students, this class, more than any other in the curriculum, fosters skills in oral, written, and visual communications, teamwork, research design, as well as technical questioning and critiquing. Many of these skills (teamwork and communication in particular) are not well-liked prior to taking the course (see Figure 5), so it is encouraging to hear students point to this class as developing their proficiency despite the disdain developed during their experiences in the general engineering curriculum (EMMA is one of their first environmental engineering program courses). As an added benefit to the ego of the instructor, the course is also cited as one of the favorites among graduates.

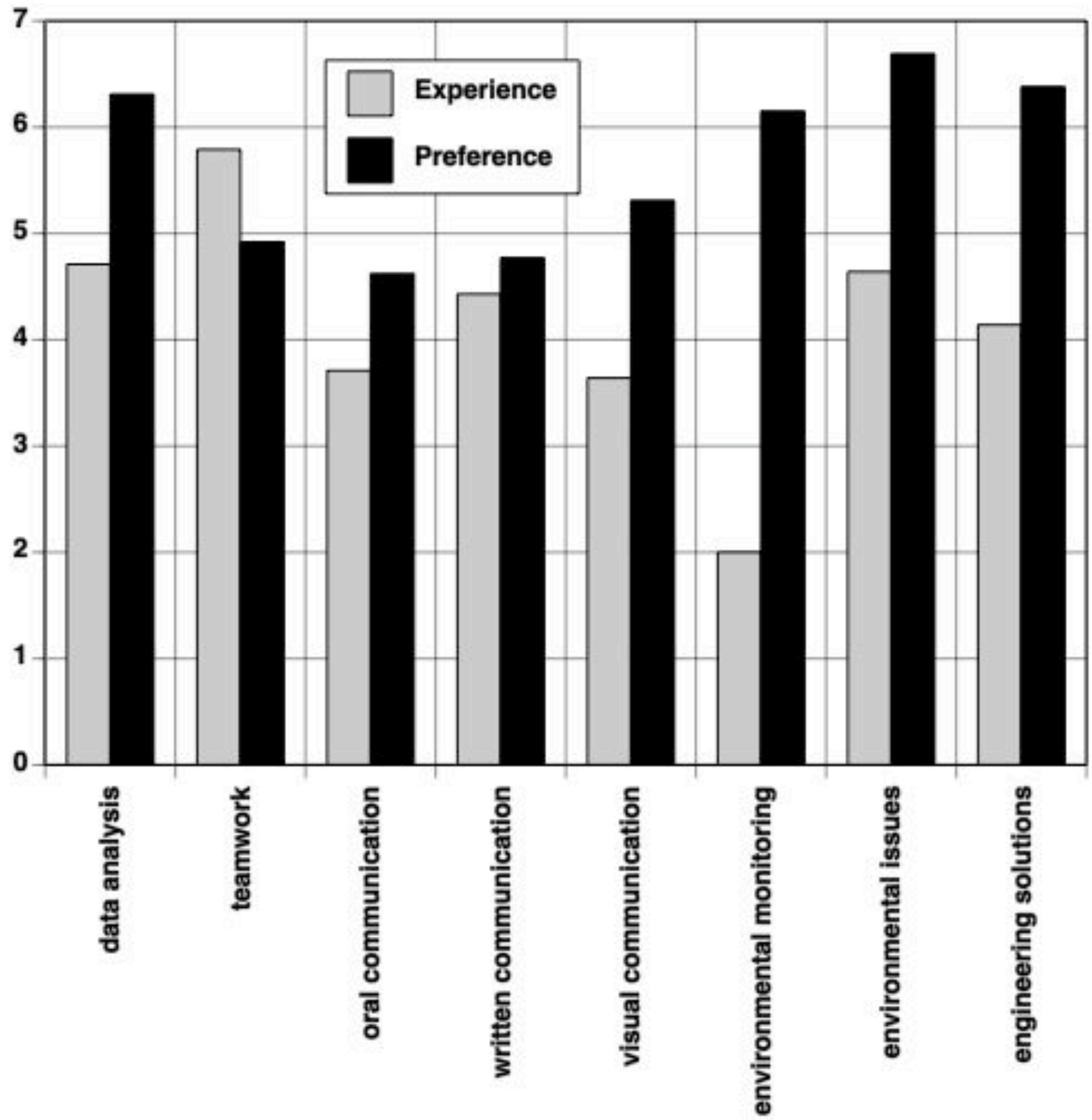

Figure 5. Average student experience with and preference for eight skill or knowledge sets central to *Environmental Monitoring and Measurement Analysis*, rated on a scale of 0 to 10. 0 is a low level of experience or preference, 10 is high level of experience or preference. Survey taken on Day 1 of class in the Spring 2006 term (n=13).

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