

## **AC 2007-438: NON-TRADITIONAL COURSES FOR APPLYING STEM KNOWLEDGE**

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# Non-Traditional Courses for Applying STEM Knowledge

## Abstract

Science, Technology, Engineering, and Math (STEM) courses traditionally teach fundamental concepts but seldom allow students to widely apply that knowledge. Ideally, students should have ample opportunities to apply previous course content to new courses, areas, and problems. The purpose of this paper is to describe two elective courses designed for science and engineering majors in their junior or senior year of a STEM program. The first course described, Atmospheric Chemistry & Physics, has been successfully implemented for four semesters while being continuously revised. The second course is in the design stage and will be ready for implementation in the next academic year. For both courses, the approach has been to create a technical course that combines content from math, physics, chemistry, and introductory engineering courses and presents the content in a variety of ways utilizing several pedagogical 'best practices'. New course content for the subject area is introduced by way of applying previously learned material to novel problems outside of traditional courses. Assessments indicate that this approach has been successful in meeting its objectives.

## Introduction

Typical courses in science, technology, engineering, and math (STEM) traditionally teach fundamental concepts but seldom allow students to widely apply that knowledge or see the wide application possibilities. This often leads to students compartmentalizing course content and to believe that after the final exam, they are ready to 'move on' to the next course. A typical curriculum then can become a series of seemingly unrelated courses (in the student's mind) that are often only connected in a senior capstone or design course. Even the typical senior capstone course usually limits the application aspects directly to the students' major and to what is considered mainstream or directly related to the discipline. Ideally, however, students should have ample opportunities to integrate and apply previous course content to new courses, areas, and problems. This should include interdisciplinary concepts and areas that may be considered non-traditional for a particular major. The courses described in this paper were designed to take advantage of proven pedagogical methods to improve student learning.

In the book *How People Learn*<sup>1</sup>, the authors arrive at several important findings including:

- Students come to the classroom with preconceptions about how the world works. If their initial understanding is not engaged, they may fail to grasp new concepts and information presented in the classroom, or they may learn them for purposes of a test but revert to their preconceptions outside the classroom. This finding requires that teachers be prepared to draw out their students' existing understandings and help to shape them into an understanding that reflects the concepts and knowledge in the particular discipline of study.
- To develop competence in an area of learning, students must have both a deep foundation of factual knowledge and a strong conceptual framework.

Bransford *et al.*<sup>2</sup> also noted that research has indicated transfer across contexts is especially difficult when a subject is taught only in a single context rather than in multiple contexts<sup>3</sup> and that when a subject is taught in multiple contexts, including examples that demonstrate wide application of what is being taught, people are more likely to abstract the relevant features of concepts and to develop a flexible representation of knowledge<sup>4</sup>. This information was integrated into the course design.

The purpose of this paper is to describe two elective courses designed for science and engineering majors in their junior or senior year of a STEM program. While the courses described have been specifically targeted at chemical engineering students, they are widely applicable to other STEM programs. The first course described, Atmospheric Chemistry & Physics, has been successfully implemented for four semesters while being continuously revised. The second course is in the design stage and will be implemented in the near future. For both courses, the approach has been to create a technical course that combines content from math, physics, chemistry, and introductory engineering courses. New course content for the subject area is introduced by way of applying previously learned material to novel problems outside of traditional courses.

This approach serves a dual purpose. First, students are required to recall concepts, principles, and ‘tools’ learned from earlier courses. This review of material helps to strengthen students’ knowledge in their core disciplines by increasing exposure to the foundation concepts. Second, students are applying both the old and new knowledge to an area outside of, but somewhat related to, their main field of study. This serves to demonstrate that they may use what they already have learned in new and interesting areas and that what they have learned to date does not exist in isolation.

An additional benefit of these applied courses is the opportunity to include consideration and discussion of various social, political, ethical, and economic topics. Such issues include global climate change, atmospheric pollution, indoor air quality, and worker safety. While such topics may also be included in many more traditional courses, these topics are often initiated by the student themselves rather than by the instructor. Because the issues are so closely related to the subject matter, the students see these connections and become interested in discussing them. This has a tremendous pedagogical advantage because the students are much more active in the discussions that were initiated by them as opposed to discussions dictated by the instructor.

Assessments in the form of concept inventories, application-oriented exam and homework problems, and survey data indicate that this approach has been successful in meeting its objectives for the Atmospheric Chemistry & Physics course.

### **Atmospheric Chemistry & Physics Course**

The course “Atmospheric Chemistry & Physics” is now in its fourth iteration and it is being continually developed to better meet the needs of the students. Although the course is open to students in any major with the appropriate math and science background, the course is tailored to the background (majors and class years) of the specific students each semester. The majority of students who have taken this course so far have been chemical engineering juniors and seniors.

Biomedical Engineering and Chemistry majors (seniors) as well as M.S. Degree candidates (Chemistry and Chemical Engineering majors) have also participated in the course. Enrollment has been between 9 and 16 students each semester.

The first day of the course begins with the students taking an open-ended concept inventory to assess their background understanding of concepts related to air pollution, clouds, atmospheric optics, aerosol particles, ozone chemistry, and greenhouse gasses. This concept inventory is not graded, returned, or discussed in class but is taken again at the end of the course as part of the final exam. The students are not told of this in advance.

In addition to the concept inventory, students are given paper and colored pencils with the instructions to draw a picture that includes, the sky, clouds, the Sun, rain droplets, a plot of how both temperature and pressure vary with height of the atmosphere, and the location of the ozone layer. This brings out several common misconceptions that the students enter the class with and serves as a discussion starter on what these misconceptions are and why they have them. As a class, the students then confront these misconceptions in a discussion format.

While the above exercise may appear remedial, recent work summarizing the research on active learning<sup>5</sup> concluded that “Taken together, the studies of Hake *et al.*<sup>6</sup>, Redish *et al.*<sup>7</sup> and Laws *et al.*<sup>8</sup> provide considerable support for active engagement methods, particularly for addressing students’ fundamental misconceptions. The importance of addressing student misconceptions has recently been recognized as an essential element of effective teaching.”

The first time this misconception-discovery activity was performed, some surprising misconceptions (not anticipated by the instructor) were identified. Some of the misconceptions that were discovered include the following incorrect beliefs by some students:

- Rain is tear-drop shaped
- The Sun is yellow-red in color
- Atmospheric pressure is cyclic or increases with altitude
- Temperature constantly decreases with altitude
- Temperature is not related to the ozone layer
- The atmosphere is only 10 km high
- Rain is blue and so are clouds

Many of their misconceptions surprised the students themselves when they analyzed their own work. They commented that although they ‘know better’ when it came to several of these concepts, some of them are strongly engrained from childhood experiences. These initial exercises involve use of the entire first day of class. On the second day, the course syllabus is presented along with the various activities students will perform during the semester and the course learning objectives. To give the reader an idea of the course content and coverage, an abbreviated list of the course overview and objectives is given below:

#### Course Overview and Objectives:

This course is designed for the science or engineering major at the junior level or above. At the conclusion of the course, the student should be able to apply basic principles of chemistry,

physics, and engineering to atmospheric systems. Specifically, at the end of this course, the student should be able to:

- Relate concepts of science to the atmosphere
- List several air pollutants
- List the layers of the atmosphere
- Describe the parameters of atmospheric models
- Calculate and explain the adiabatic lapse rate
- Sketch the temperature and pressure profiles of the atmosphere
- Predict the lifetime of a pollutant
- Summarize the cycling of elements
- Argue a position on climate change
- Define what is meant by an aerosol
- Identify the main greenhouse gases
- Explain how clouds are formed
- Apply knowledge of physics to the movement of aerosol particles
- Assess the effects of aerosols and clouds on the climate
- Solve for the production or loss rate of a chemical species undergoing reaction
- Estimate the amount of a chemical species in the entire atmosphere
- Select the best control strategy for a given pollutant or set of pollutants
- Explain why the sky is blue
- Compare tropospheric ozone to stratospheric ozone
- Defend a position on a control strategy for the acid rain problem
- Question the scientific evidence behind various atmospheric problems and issues
- Challenge the degree of scientific certainty required to justify environmental actions

The course objectives are met through a mixed application of teaching strategies and activities. The students have a main textbook for the course (*Introduction to Atmospheric Chemistry* by Daniel J. Jacob)<sup>9</sup> but are supplied numerous supplementary material from other sources<sup>10</sup>. One major source of supplementary information is from current news articles and reports related to the atmosphere. These are presented throughout the course in the context of demonstrating the importance, usefulness, and motivation for understanding the Earth's atmospheric chemistry and physics.

The topics addressed in the course lead to coverage of a variety of basic scientific ideas and principles including:

- Units and unit conversions
- Differential equations
- Gas laws
- Partial pressures
- Phase diagrams
- Steady-state and equilibrium
- Barometric law
- Models and simplifying assumptions

- Lifetime, residence time, half-life, and renewal time
- Mass and energy balances
- Fluid dynamics, turbulence, and Reynold's number
- Thermodynamics
- Biogeochemical cycles
- Henry's law
- Acid dissociation
- Radiation, black bodies, and spectroscopy
- Optics
- Chemical kinetics, photolysis, and radical chemistry

Students are given homework problems that are a mix of technical calculations and open ended concept or discussion questions. They are encouraged to work in small groups on these assignments and some class time is used for problem sessions on particularly challenging assignments.

Examinations include a mix of in-class and take-home problems as well as open-book and closed-book sections. This permits students to demonstrate the basic knowledge they should be able to recall or solve without reference (Bloom's Taxonomy<sup>11</sup> levels of knowledge, comprehension, and application) and also to demonstrate their ability to think through and research more complicated problems and to compose their thoughts on essay questions (Bloom's Taxonomy levels of analysis, synthesis, and evaluation). In addition to permitting the testing of various levels of Bloom's Taxonomy, this method of testing provides a mix of test-taking formats to benefit students with a variety of test-taking strengths and weaknesses thus accommodating a variety of learning styles.

Team research topics are an important component of the course. Research projects are also performed in various ways to appeal to students with different strengths. The first project is a team-based project related to a known atmospheric problem such as urban smog, the ozone hole, or acid rain. This project culminates in a formal presentation to the entire class. This presentation is meant to be included as actual course content for which the class is responsible. The presentation is therefore usually about one hour long and includes the students leading the class in example problems and/or discussions. Feedback from student surveys indicates that this project is extremely valuable to the students. They indicate that they learn this material better than any other paper-writing or presentation format because they have to be able to teach it back their classmates.

The second project involves teams of different composition than the first project teams. This permits students to work with a variety of individuals and not just their closest friends or neighbors. This project usually covers some aspect of the global climate system such as the effects of water on climate or human impacts. This project involves a more standard presentation (about 30 minutes) and a final written report.

The final project is an individual project on a subject of each student's choosing that is somehow related to the atmosphere. Each student not only gets to select a topic of interest, but they also can choose the nature of their final report. They can either write an individual paper or present

their results individually to the class. Most students, although initially nervous about doing an individual presentation, usually select the presentation over the paper. This presentation is a good way for students to practice their presentation and speaking skills and to help develop self-confidence.

A final part of the class involves hands-on activities, demonstrations, and a field trip. A useful guide to such demonstrations is the book *Clouds in a Glass of Beer* by Craig F. Bohren<sup>12</sup>. These demonstrations include:

- Water absorption by sodium chloride particles
- Reduced relative humidity over a water solution
- Water condensation on particles due to relative humidity mixing
- Particle formation from cooking and smoking
- Particle concentration measurement
- Nucleation of gas bubbles in beer (inverse cloud)
- Sky in a jar (why the sky is blue and sunsets red)
- Secondary aerosol formation from VOC and ozone
- Homogeneous nucleation clouds
- Aerosol-light interactions

Mini field trips taken during normal class hours involved visiting an aerosol research laboratory on campus, a roof-top meteorological and air sampling station, and outdoor atmospheric observations including heterogeneous nucleation (mixing clouds) from a local power station. These trips allowed students to see the equipment used in collecting data and performing atmospheric experiments in a laboratory setting and to gain a better appreciation for how they function and the limits of what they can do.

The final major class activity was a field trip to the Marian Koshland Science Museum of the National Academy of Sciences in Washington, D.C. This museum is dedicated to only two exhibits, one of which has been climate change. Students took an independent audio tour of this museum and had the opportunity to work with many hands-on exhibits and learn about numerous topics related to climate change and global warming.

Class time not used for any of the above activities consisted of a mixture of short lectures and active-learning components. Each class made links with the earlier classes and connected with information from other courses such as chemistry and physics. Classes utilized the Kolb Cycle<sup>13</sup> of learning with a format that followed the “Why?, What?, How?, and What if?” cycle. Each class period began with a review of what was done in the previous class, followed by an introduction and motivation for the next topic. Next, the new information was presented and students were given opportunities to apply the new material to example problems and homework problems. Finally, class discussions and research projects provided students with opportunities to share with their peers, look at the “big picture” context, and be evaluated and provided with feedback from the instructor.

## **Particle Technology Course**

The course “Particle Technology” is a new course that is still under development. This course will be open to students in many majors with the appropriate math and physics backgrounds but will most likely be attended by engineering and physics majors. The course will cover the applications, production, processing, and measurement of particles ranging from the molecular scale to the large macroscale. This will include particles as small as ‘buckyballs’ and as large as marbles. Particle technology is important in wide a range of applications including:

- Pharmaceutical production
- Drug delivery
- Atmospheric pollution
- Nanotechnology
- Paints and coatings
- Industrial chemicals
- Agricultural products

Although there is no single textbook that covers the full range of interest and applications of this course, the likely required textbook will be *Introduction to Particle Technology* by Martin Rhodes<sup>14</sup>. Supplemental information from a range of books and recent news stories and publications will be used frequently.

As with the other course, the first day of the course will begin with the students taking an open-ended concept inventory to assess their background understanding of concepts related to particle technology. This concept inventory will also contain multiple choice questions designed to bring out common misconceptions that the students hold before taking the course. As a class, the students will then confront these misconceptions in a discussion format.

To give the reader an idea of the course content and coverage, an abbreviated list of course topics is given below:

#### Course Topics:

- Particle applications and importance
- Particle basics
- Size-dependent motion
- Size distributions
- Settling and agglomeration
- Analysis methods
- Packed beds
- Fluidization
- Spray dryers and cyclones
- Storage and flow
- Mixing and segregation
- Size control
- Safety and hazards

Much of the course design and pedagogy is similar to the Atmospheric Chemistry & Physics course. One area of significant difference in how the Particle Technology course is taught is the inclusion of hands on exploratory laboratories throughout the course. These laboratories will not be the more traditional 'cook book' type labs but rather ones offering a strong 'exploration' feel where students will operate equipment under supervision and try to figure out how it works and what can be done with the equipment. These laboratories include the use of particle generation technology such as spray dryers and atomizers as well as particle analysis technologies including an in-line particle sizing device for particles suspended in a gas flow and a particle sizing device for those suspended in a liquid. Additional experiments involve generation of nanoparticles from gas-to-particle conversion and the measurement of their loss rates due to coagulation and surface deposition. Further experiments that are planned include the use of diffusion separators, electrostatic devices, filters, and sieves for particle separation. This equipment can be used in several ways for students to perform numerous experiments. One of the planned objectives will be for a final course project where the students design and test a new laboratory experiment.

There is much research supporting this discovery-learning format. The Carnegie Foundation's report, *Reinventing Undergraduate Education: A Blueprint for America's Research Universities*<sup>15</sup> famously quotes John Dewey as saying "Learning is based on discovery guided by mentoring, rather than by the transmission of knowledge." A follow-up report based on a conference sponsored by the Reinvention Center<sup>16</sup> concluded the "the implementation of more inquiry-based teaching...can result in substantially increased understanding among our students." While this report was focused on the biology curriculum, it should apply equally well to any STEM program.

The problem-based laboratory approach described above helps to address many of the desired outcomes of an undergraduate education identified by Duch et al.<sup>16</sup> including:

- Think critically and be able to analyze and solve complex, real-world problems
- Find, evaluate, and use appropriate learning resources
- Work cooperatively in teams and small groups
- Demonstrate versatile and effective communication skills, both verbal and written
- Use content knowledge and intellectual skills acquired at the university to become continual learners

Homework and examinations for the Particle Technology course will also follow the pattern of the Atmospheric Chemistry & Physics course giving students a variety of exposures, opportunities, and learning formats.

Team research topics will be included along with the laboratories. These will include opportunities for students to perform presentations traditionally, as a lecture format, and to write papers. There will also be an opportunity for an individual research project. Although there will be some simple demonstrations of particle phenomena, the majority of the visuals will be manifest in the hands-on exploratory labs.

It is the intention of the instructor to provide a few class field trips to see first-hand how large and small particle handling systems operate. These field trips will include the handling of fine

particulate fly-ash from a power plant and the handling of corn/grain on a large commercial farm.

Class time not used for any of the above activities will again consist of a mixture of lectures and active-learning components with each class linked to earlier classes and connected with information from other courses such as chemistry and physics. The variety of teaching methods and styles incorporated by the instructor include traditional lectures, class activities, discussions, Socratic questioning, Powerpoint presentations, student instruction, cooperative and problem-based projects, demonstrations, discovery laboratories, online interactive simulations, etc. By rotating through methods which appeal to visual, auditory, and tactile learners, every student is exposed to both their preferred learning style as well as alternative methods.

### Assessment

Assessments in the form of concept inventories, application-oriented exam and homework problems, and survey data indicate that this approach has been successful in meeting its objectives for the Atmospheric Chemistry & Physics course. Concept inventories for the course were developed by the instructor and are still being improved. Last semester the class average was 30% correct as a pre-test and 90% correct after the course was complete. The concept inventory currently being used involves 14 multiple-choice questions and 7 short answer questions. Examples of some of recently used concept inventory questions are given below:

- a. A chemical species with similar concentrations over the ocean and inland most likely has a residence time in the atmosphere that is
  1. Very short
  2. Very long
  3. It is impossible to tell
  
- b. If there are several mechanisms (not steps) by which a species is removed from the atmosphere and each mechanism has a specific time constant associated, the overall removal is dominated by
  1. The fastest time constant mechanism
  2. The slowest time constant mechanism
  3. The squared sum of the time constants
  4. The difference between the fastest and slowest mechanisms
  
- c. The processes of evaporation and condensation are considered to be in
  1. Steady state
  2. Pseudo-steady state
  3. Dynamic equilibrium
  4. Static equilibrium
  
- d. Which would have the highest vapor pressure above it?

1. Pure water, flat surface
  2. Salt water, flat surface
  3. Pure water, curved surface
  4. Salt water, curved surface
- e. When a gas-phase species is said to be soluble in water, it means that there is a higher concentration of the species in the aqueous phase than
1. There is of other species in the aqueous phase
  2. There is in the gas phase for the same species
  3. There is in the gas phase compared to another species
  4. Traditional Henry's law would predict
- f. Nucleation is the first step of phase changes. In the atmosphere this is the change of gas-phase water to liquid-phase water. Which of the following mechanism best describes atmospheric nucleation:
1. At high supersaturations pure water molecules combine only with themselves.
  2. At temperatures near 0 K water molecules slow down to combine with each other.
  3. Critical-sized clusters of pure water grow into cloud droplets under low supersaturation conditions.
  4. At low supersaturations, water molecules condense first on a foreign substances which act as the nucleation points for further water condensation.
- g. In the atmosphere, photochemistry occurs when molecules are produced with excited-state electrons from interaction with solar radiation. Once excited, these molecules may do which of the following: (circle all that apply)
1. Lose energy by radiation emission
  2. Reach a higher excitation state by collision
  3. Directly react with another molecule
  4. Become deactivated by collision with another molecule
- h. Which one of the following is NOT considered a 'greenhouse gas':
1. Water vapor
  2. Carbon Dioxide
  3. Methane
  4. Ammonia
  5. CFC's

- i. The Earth may be considered as a black-body emitter at
  1. Absolute zero
  2. 300 K
  3. 6000 K
  4. 1,000,000 K
  5. There is no radiation emitted

Surveys are conducted at the beginning of the course to gauge student interests and expectations, during the first half of the course to gauge student progress, and at the end of the course to provide feedback for the next time the course is taught. Survey data continue to be very positive with the course receiving an evaluation average on the question “I would recommend this course to others in my field” of 4.8/5.0 (where 4 is “agree” and 5 is “strongly agree”). Specific feedback from student evaluation has been utilized to change the course textbook, alter the format of exams, improve the homework assignments, and tailor the course content to the students’ interests. Similar assessments and evaluations will be performed on the Particle Technology course when it is implemented. Some of the recent student responses to the question “What aspects of the course did you like most?” were:

“I like the flexibility and the connections that the material has to the everyday world.”

“I most enjoyed the group presentations – I think these best helped me learn a topic very in-depth.”

“I like that this course teaches you something you don’t usually learn in chemical engineering. I like the fact that the knowledge we have can be put towards understanding how the atmosphere works and what affects it. I find it very interesting.”

“Very interactive and keeps me attentive for a good portion of the 2-hour class.”

“Interesting subject matter. I like the way it is tied to current environmental issues.”

“The material was presented in a way that stimulated my curiosity and allowed me to fully understand how the atmosphere works.”

## **Summary**

Two new, non-traditional courses have been developed that are applicable to students in a range of academic majors. These courses, Atmospheric Chemistry & Physics and Particle Technology, do not require specialized backgrounds or prerequisite courses but rather call on the use of knowledge from the general areas of science, technology, engineering, and math. The courses are designed to work best when students with varying backgrounds work together on team projects and/or laboratories in a collaborative environment where they can learn from one another. The courses incorporate a range of pedagogical ‘best practices’ including active learning, identification of misconceptions, use of all the levels of Bloom’s Taxonomy, Kolb’s learning cycle, and opportunities to address every student’s preferred learning style and method of evaluation. Assessment and feedback mechanisms are in place and the courses are constantly under refinement to meet the needs of the students and the changes in industry, society, and technology.

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