Teaching Chemical Equilibrium Concepts Using Field-Lab Experiences In A Multi-Disciplinary Integrated Environment

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Abstract: An integrated inquiry-based experience centered around a field trip to the Huffman Dam on Mad River, Dayton, Ohio, was designed for pre-education science students preparing to become teachers at the primary and secondary level. We used chemical equilibrium to illustrate the hypothesis that students learn equilibrium concepts better when engaged in a combination of field and lab experiences than when taught in a traditional setting. Students did not gain anything in a traditional setting. However, the content normalized gain index was 0.60 when chemical equilibrium was taught using this inquiry based field-lab experience in an integrated environment. Chemical equilibrium theory was taught by applying its concepts to understand water quality in the Mad River. Water quality was analyzed and explained as being impacted by the mineral dissolution from the surrounding rock. As a result, students appreciated learning equilibrium chemistry through an integration of chemistry, hydrology, and geology. The purposes of the chemical equilibrium lesson were to employ inquiry methods to learning science; hands-on approach in gathering data; evaluation of data in understanding scientific theory and application of inquiry, and evaluation in the classroom. Activities are described and illustrate in detail how the geology and chemistry content of chemical equilibrium were integrated and evaluated.

Introduction:

Recent science education reform efforts have encouraged the development of "hands-on" laboratory and field activities to improve undergraduate and graduate science courses. In addition, many science education reform recommendations call for active learning styles that develop critical thinking and problem-solving skills rather than passive learning. This article describes a teaching approach in the Dayton, Ohio area to help students actively investigate quality of water in Mad River, Dayton, Ohio, using the concepts of chemical equilibrium. Chemical equilibrium has historically been a difficult topic for undergraduates to learn in a meaningful way. As part of the introductory chemistry and geology course for pre-education teachers, we have the students 1) participate in an investigative field trip to Huffman Dam, on the Mad River, that provides analysis of the water along the river near the dam, and also from the nearby geological outcrop 2) collect samples and measure water quality parameters 3) search the USGS website and compare their measurements to the on-line data. The field trip allows students to make direct observations, collect scientific data, and experience the connection between the geological context and water quality in the area using chemical equilibrium.

The approach used in the course is unique in that observations students make in the field measuring the water above and below Huffman Dam assist their forming tables of data for the inquiry activity on chemical equilibrium. Numerous studies have demonstrated the educational effectiveness of field experiences, but few studies have reported on the influence of laboratory and field experiences *(1-4)*. This chemical equilibrium module connects field trip observations with laboratory modeling in an introductory course for pre-education teachers to understand science as a process, and subsequently to teach science concepts in a meaningful way.

Background:

The research team that created and assessed the chemical equilibrium module at Wright State University, Central State University and University of Dayton was part of the Ohio Higher Education Network (OHEN) sponsored by State of Ohio funding. Individuals working on the OHEN were to promote change in the instruction of undergraduate science courses, especially those taken by pre-education teachers, and to enhance students' understanding of science concepts. The research team for this OHEN project included faculty members from the Department of Chemistry at Wright State University, the Water Resources Department at Central State University, and the Geology Department at University of Dayton. Such an interdisciplinary team was designed to provide pre-service teachers taking chemistry multiple perspectives in the inquiry-based lesson that would integrate water quality and geology concepts. This particular chemistry inquiry lesson was developed as part of a required chemistry course for Middle Childhood Education undergraduate pre-service teachers and graduate students majoring in Interdisciplinary Master of Science in Teaching. Content knowledge built in an inquiry-based mode includes heat and temperature, kinetics, equilibrium, acids and bases, electrochemistry, and organic chemistry. The mathematics prerequisite is Fundamental Mathematics Concepts which includes basic college arithmetic, algebra, and trigonometry. The purpose of the course is to prepare pre-service teachers who may currently lack skills to train their future students to attain process skills necessary to satisfy the national and state standards and also to face global competition in science achievement. This course also prepares science teachers to teach concepts in chemistry as applied to real world problems using a cross-disciplinary approach. The chemical equilibrium chapter was used to investigate teaching chemistry by choosing examples across disciplines. Accordingly, this chapter was taught using water quality as an example on a backdrop of a river and a geologic outcrop. Students are not required to be experts in geology or water quality. The basic concepts of water quality and geology required are introduced to the pre-service education teachers/students during the field trip. The chapter included definition of equilibrium, equilibrium constant, homogenous and heterogeneous reaction equilibrium, Henry's law, law of mass action and solubility product. We will discuss the evaluation technique that was used to determine how the integrated approach affected the student's conceptual understanding of chemical equilibrium *(5).*

Our teaching method included: 1) a field trip to the Huffman Dam along the Mad River, Dayton, Ohio 2) having students make observations of the environment around them with such questions asked as: What rock observed by the bedrock provides calcium in water?; What is limestone and do you find any at the Huffman Dam?; How do these minerals affect the chemical composition of water near the bedrock and water that runs off into the Mad River?; How does the fertilizer applied on the Mad River watershed affect the quality of water in the river?
3) Prompting students to use their observations to develop scientific hypotheses and make measurements of pH, dissolved oxygen, temperature, turbidity, concentration of phosphates, nitrates and carbonates, upstream and downstream of Huffman Dam. In the field, pre-education students also collect samples of rocks, soil and fossils in addition to measuring the water quality parameters such as pH of the water and soil. In the laboratory, students measured total hardness and also calcium hardness in the samples collected from the field trip *(4),* providing students an opportunity to construct their knowledge by working through an inquiry packet on chemical equilibrium. The inquiry packet, included in the Teacher's Guide provided as supplement to this manuscript, was designed to associate the measurements made both in the field and the laboratory with concepts on chemical equilibrium. Measurements such as pH and dissolved

oxygen were compared with predictions of these parameters using theory of chemical equilibrium. Concentrations of phosphorus and calcium were measured both in the field using Hach instruments and in the laboratory. These measurements were compared with predictions assuming these ions are in equilibrium with minerals such as limestone and dolomite present in rocks and soil in this region. Thus, the concept of chemical equilibrium was reinforced through proper integration of chemistry, quality of natural water in the river, and dissolution of rocks and minerals in soil. Such an integration was accomplished through the involvement of instructors from Chemistry education, Water Resources and Geology *(5.)* During the field trip, students were actively working as scientists rather than having them read about or listen to lectures about what has been found at Huffman Dam. Students conducted scientific work by making observations on the river near the Huffman Dam, developing hypotheses that water quality can be predicted using equilibrium chemistry and testing their hypothesis. The role of an instructor is to assist student exploration and discovery by providing opportunities for them to make observations. This OHEN approach motivates future teachers to teach science as a process by incorporating similar teaching approaches in their science classrooms *(7-9)*. In order to assess this new approach using a combination of lab and field experiences, instructors compared the inquiry method with traditional lecture methods. The lecture method involved covering the chapter on Chemical Equilibrium from the prescribed textbook. Students were taught in the traditional lecture mode first and then the guided inquiry method. The same pre-test and post-test were administered for both methods of instruction.

Experimental Details

Water samples were collected both upstream and downstream of the dam. Water quality measurements required the following materials. 1) A low-cost estuary and marine test kit from

LaMotte was used to test for phosphate (www.lamotte.com/pages/common/pdf/instruct/5971). A phosphorus test tab was added to 10 ml of water sample. The test tab contains ammonium molybdate which reacts with orthophosphate to produce a phosphomolybdate complex. This complex when reduced by stannous chloride or ascorbic acid produces a blue color. A phosphate color chart was used to match the color obtained with the sample to record its phosphate content (http://www.lamotte.com/pages/edu/ind-kits/phosphat.html). An Enviro-Safe Pocket Thermometer from Sigma-Aldrich was used to record the temperature. 2) The pH of the samples was measured using a pHep sensor by Hanna (Model No. HI 98107). The pH probe was calibrated using standard pH buffers 4, 7 and 10 before actual measurement. Once calibrated, the instrument could be used to measure pH. 3) The total carbonate was determined in the lab by titrating a 50 ml sample with 0.02 N sulfuric acid to pH 4.3. The titration was followed by using phenolphthalein indicator until pH 8.3 and methyl orange indicator until pH 4.3. 4) The calcium hardness was measured using a Hach total calcium and magnesium hardness water kit (Model HA-4P-MG-L). The hardness was essentially from calcium and magnesium bicarbonates. It was found by titration using EDTA. The hardness in mg/L was reported as equivalent of calcium carbonate. The detailed procedure for testing calcium hardness is available at the Hach website www.hach.com. 5) The dissolved oxygen was also measured using a Hach dissolved oxygen (DO) kit (Model OX-2P) which uses a modified Winkler method. The stepwise procedure for finding dissolved oxygen is available at the Hach website www.hach.com.

No chemicals or procedures used by students present any significant hazards; however, nothing should be ingested. Protective garments and gloves should be worn at all times. Hands should be washed after all sampling. Also, students should be warned against drinking their samples at ANY time before, during, or after collection and testing.

Results:

Student performance was assessed using pre- and post-tests. The methodology included administering a pre-test, conducting a field trip, performing lab analysis, interpreting measurements using a guided inquiry and finally taking a post-test. Pre-tests and post-tests were administered to assess the knowledge gained on chemical equilibrium by the pre-education students enrolled in the chemical education course at Wright State University. The guided inquiry (see Teacher's guide) uses carbonate equilibrium since it controls the chemistry of natural water. The Mad River drains from a watershed that has a calcite bed underneath. Relevant equations describing carbonate equilibrium and calcite dissolution were included. The reactions included dissolution of carbon dioxide and oxygen gases from air, aqueous speciation, and calcite precipitation and dissolution. The guided inquiry then allows students to tabulate data gathered from field and laboratory. The following table shows typical data obtained from a field trip to Mad River Ohio by the Huffman Dam.

Location/ Parameter	Flow	Temp.(^{0}C)	pH	Dissolved Oxygen (mg/L)	Calcium Hardness (mg/L)	Total Carbonate (mg/L)	Phosphate mg/L
Upstream	Slow	22.3	8.7	9.4	180	0.0024	4
Downstream	Fast	23.1	8.4	9.2	140	0.0020	2

Then the guided inquiry allowed teachers to predict dissolved oxygen (DO) both upstream and downstream using Henry's law. The students verified the calculated DO with measured DO on the stream and using a nomograph. They compared the orthophosphate levels measured on the stream with estimated values assuming calcium phosphate as the controlling solid phase. They also estimated pH upstream using carbonate equilibrium and compared with the observed pH on the stream. The estimated value was in close agreement with the measured value.

Questions in the guided inquiry were based on two phase equilibrium between water and air; determination of pH upstream and downstream of the dam by solving aqueous phase chemical equilibrium, and prediction of pH of water near the outcrop using equilibrium between aqueous phase carbonate species and solid phase mineral calcium carbonate. There was no lecture in the guided inquiry. Student learning had taken place through experiences in the field trip, basic information provided on water quality and geology, lab experiences, and guided inquiry.

The authors used the traditional mode of lecture and reading from the prescribed textbook prior to adopting this guided inquiry. The traditional method was employed to the same class and was preceded by a pre-test and followed by a post-test. A handout on chemical equilibrium comprising of the chapter from the textbook and supplementary notes was distributed to the students. The instructor used the handout to teach concepts. The students enrolled into this education class for middle school childhood teachers who did not have any prior background on chemical equilibrium and their background in basic chemistry was found to be weak. This reflected as zero scores on their pre-test. Most students returned their pre-tests indicating that they were unaware of the concepts how reactions related to real world problem solving based on chemical equilibrium incorporating soil and water quality. Since the handout only focused on describing the general concepts and theory with few examples to real world analysis, students could not apply themselves to solve the problems on the post-test. A combination of lack of problem solving ability and deeper understanding of the concepts among students when taught using the traditional method may have contributed to their similar performance on the post-test. The time allotted for teaching this chapter was one week in the traditional setting which made any enrichment using laboratory exercises difficult. The lack of any comprehension using the traditional method to a class with weak/no prior background in chemistry encouraged instructors to adopt the above discussed guided inquiry approach integrating concepts across chemistry, geology and water resources. The field trip provided association of abstract concepts to concrete examples such as water, rocks, and minerals.

With the traditional mode of lecture, students had no prior understanding of the concepts on chemical equilibrium (0% on pre-test) and also there was no gain achieved from the traditional lecture (0% on post-test). However, in the inquiry mode of teaching an average pre-test score of 0% and an average post-test score of 60.0% with a normalized gain of 0.60 was attained. The class standard deviation was found to be 18%. Normalized gain was calculated using the formula: (post-test - pre-test) / (100-pre-test). The pre-test/post-test was included in the Teacher's guide. These results were obtained for a class of 35 students. As discussed before both the traditional mode and inquiry mode of teaching were carried out each for one week period. The resulting 60.0% increase in percentage points from the pre- and post-tests results of 35 students are consistent with the noted trend of improved student understanding with increased interactive science courses. In addition to the pre- and post-tests, the pre-education students in the OHEN project were given a questionnaire about their views on science instruction and teacher preparation. An analysis of this survey suggests that teaching concepts in chemistry using a combination of field trips and laboratory work reinforces an undergraduate science teacher's opinion about science instruction using inquiry *(9-10)*. The pre-service teachers who are education majors expressed greater comfort in learning these concepts using a real-world application such as prediction of water quality in a river. Overall, the pre-education students' comments regarding this inquiry-based chemical equilibrium packet have been positive and enjoyable compared to the traditional lecture on chemical equilibrium.

Conclusion:

Integration of the field trip and laboratory experiences was an effective learning mechanism that allowed students to make the connections between field observations and more abstract water quality concepts (oxygen concentration to temperature correlation, estimation of pH using law of mass action equations etc.). This approach is particularly useful to teach education pre-service majors who lack rigorous science content compared to science majors. Field trip would provide concrete experiences to facilitate understanding of abstract equilibrium concepts. This methodology can be applied to any college level of chemistry or environmental courses intended for education majors who would be teaching these courses in turn to their students. We stress that the student understanding of content gained during this course was not by volume or variety of course but by how the content was actively discovered by students in multiple learning environments. The results of this study are consistent with previous research that demonstrates field experiences attract students to science and make science learning more meaningful. This chemical equilibrium activity also adds to the integration of mathematical skills, laboratory skills and geology content as well. The students were given a guided inquiry lesson (see Teacher's guide) that required students to read and compile data at the Huffman Dam on pH, dissolved oxygen, phosphates, nitrates, and carbonates. This data were interpreted using simple concepts on chemical equilibrium. A pre-/post-test as shown in Teacher's guide was given to students to assess the content gain. The questions were designed in such a way that one can asses students' ability in comprehending the lesson provided through guided inquiry included in Teacher's guide, applying the lesson to analyze water quality in the river, analyzing the data collected from making measurements on the river and then synthesizing the overall results using chemical equilibrium to understand water quality by the Huffman Dam along the Mad River, Dayton, Ohio. It was found that students were excellent on comprehension and application of chemical equilibrium and were above average for the analysis and synthesis of the inquiry-based chemical equilibrium lesson as noted giving an overall 0.60 normalized gain. This field and lab experience has created real-world experiences that students will utilize as future teachers in their own classrooms *(9-10)*.

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