Effectiveness of a high-altitude balloon project compared to conventional environmental science laboratory projects conducted by undergraduate students in an environmental chemistry course

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High-altitude balloon projects have been incorporated into undergraduate courses for both science and non-science majors because of their unique aspects, including inexpensive access to the near-space environment and exposure to engineering principles associated with flight package design. The current project focuses on an intermediate population of 20 students taking a class in environmental chemistry during the spring of 2013. Most of these students are in DePaul's bachelor of arts program in environmental studies, which does not require the core sequences in math, physics, chemistry, and biology. The students will participate in either high-altitude balloon projects or standard environmental science projects (for example, water quality measurements). Research provides substantial evidence for the positive correlation between science achievement and affective factors such as motivation, attitude, and believes. Furthermore, the unique experience of balloon research has been shown to result in significant improvement in students' motivation, science learning, and thinking skills. Thus, we hypothesize that the unique nature of the high-altitude balloon projects will create better attitudes about learning science as measured by the *Colorado Learning Attitudes about Science Survey* at the end of the quarter, and that this will translate into a greater increase in the understanding of chemical concepts as measured by changes in the *Chemical Concepts Inventory*.

I. Introduction

Scientists and engineers are very familiar with both summative and formative uses of evidence. We use summative evidence when we publish the results of research studies that confirm or refute the predictions of a theory, or analyze of how well new processes or products meet given specifications and constraints. Even though it rarely leads to publications, we also rely on formative evidence during the exploration phase of our research, for example when we analyze preliminary observations and conduct exploratory experiments to come up with interesting research questions and determine the direction of more formal, rigorous and expensive future investigations. In contrast, we rarely take advantage of formative evidence when we assess the effectiveness of our instructional methods. Instead, we tend to rely on summative evidence, for example in the form of final exam grades. While this form of assessment is necessary, we often get the results when it is already too late to change instruction.

In 2009 we started integrating high altitude ballooning (HAB) into the curriculum of courses for non-science majors, and in 2012 also into courses for science majors. HAB projects are often more time-consuming and more expensive than other instructional methods, so it is important to know whether it is worth the additional cost and effort. How might we assess the effectiveness of HAB in helping students learn science and how it affects their attitudes about science? Of course we already had some of this information from exams, course evaluations, and university wide assessment projects. However, these methods were not adequate for more detailed information about student learning and attitudes.

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II. Assessment Methodologies

A. Attitude Surveys

There are a number of validated assessment tools that probe student attitudes, beliefs, and expectations about science. The Colorado Learning Attitudes about Science Survey for Chemistry[1] (CLASS-Chem) is designed to measure the shift in student beliefs between the beginning and the end of a course. It consists of 50 statements to which students respond on a 5-point Likert scale. For example, statement 9 reads: "When I solve a chemistry problem, I locate an equation that uses the variables given in the problem and plug in the values." Students are then asked to respond on a 1-5 scale, where 1 means that they strongly disagree with the statement, 3 means that they are neutral, and 5 means that they strongly agree. A student's "overall % favorable score" is the percentage of responses that agree with the expert's response, and the "overall % unfavorable score" is the percentage of responses that disagree with the expert's response. The CLASS-Chem is based on the premise that effective instruction should change student attitudes and believes from those held by novices towards those held by experts. To determine what the expert response is, the survey has been given to a large number of faculty at different universities. Other student attitude surveys that focus specifically on chemistry include the Chemistry Expectations Survey[2] (CHEMX), which measures changes in students' cognitive expectations for learning chemistry and the Chemistry Self-Concept Inventory[3] (CSCI), which assesses students' self-concepts as learners of chemistry.

While student attitude surveys such as the CLASS-Chem, the CHEMX and the CSCI can provide important insights into student perceptions about their learning, they are not reliable indicators of what students actually learn because they depend on self-assessment. To determine how well students can predict their own performance in science, Bramble and Workman[4] asked environmental science majors to interpret graphs in pre- and post-course assessments. They found that there was very little correlation between how students thought they performed and how their responses were scored by faculty evaluators. Similarly, Bowers, Brandon and Hill[5] administered a survey consisting of biology content questions and found that there was no correlation between the students' confidence in their performance and their actual scores. In both studies students significantly overestimated their understanding of science concepts. In contrast, Metz[6] reports on a study in which students took weekly online quizzes in an introductory science course and underestimated their performance compared to their actual scores.

B. Concept Inventories

To obtain more reliable insights into how well students learn important science concepts, a number of so-called concept inventories (CI) have been developed. CIs can help instructors recognize student misconceptions and measure gains in understanding as the course progresses. The first CI that was widely used by faculty is the Force-Concept Inventory[7] (FCI), which is designed to assess student understandings of basic concepts from Newtonian mechanics through multiple-choice questions consisting of both the correct (according to Newtonian mechanics) answers and common sense alternatives that are inconsistent with Newtonian mechanics. Similarly, the Chemistry Concept Inventory[8] (CCI) is designed to measure the extent to which students hold intuitive but incorrect conceptions about high school and introductory college chemistry topics. It consists of 22 multiple-choice items, many of them in linked pairs where the first question probes for content knowledge and the second question probes for the correct reasoning. For example, questions 16 and 17 test students' conceptual understanding of heat versus temperature. Question 16 explains that it takes longer to raise the temperature of a given volume of water by a certain number of degrees than to raise the temperature of the same volume of alcohol by the same number of degrees. It then asks students which of the two liquids received more heat. Question 17 provides several possible explanations for the answer to 16 and asks students to select the correct one. In addition to the FCI and CCI, there are many other concept inventories that measure students' conceptual understanding in a variety of disciplines, such as the Light and Spectroscopy Inventory[9], the Greenhouse Effect Concept Inventory[10], and the Astronomy Diagnostic Test[11].

High-altitude balloon research is a unique experience that many students find exciting and enjoyable. HAB experiences have been shown increase student motivation and improve learning and thinking skills[12]. In addition, there is convincing evidence that affective factors such as motivation, attitude, and believes are positively correlated with science learning[13,14,15]. Thus, the purpose of this research is to investigate whether including an HAB experience in an environmental chemistry course results in measurable changes in content learning and attitudes.

III. Case Study

A case study using these assessment tools was designed to test the hypothesis that the HAB experience was more effective at increasing student understanding of chemistry compared to more traditional environmental chemistry projects.The vehicle for the experiment is a class taught in DePaul University's Department of Environmental Science and Studies, Chemistry of Earth Systems (ENV 316). This is an upper-level undergraduate class for both bachelor of arts (BA) majors in environmental studies and bachelor of science (BS) majors in environmental science. The class focuses on the impact of pollution on the Earth system's ability to provide clean air, water and energy. The industrialization of the economy during the last 150 years has greatly increased the amount of waste that is sent into the four Earth spheres: the atmosphere, hydrosphere, lithosphere and biosphere. These emissions directly harm organisms and also cycle back to pollute essential ecosystem services provided by the Earth. The class also considers the source, transport, transformation and ultimate fate of pollution emitted into the air and water. A prerequisite to the class is Earth System Science, which explored the basic workings and interactions of the four Earth spheres. Chemistry of Earth Systems also had the goal of fulfilling the environmental chemistry requirement for environmental studies majors, and used the American Chemical Society's textbook, Chemistry in Context (7th edition, 2012). The course began with air quality issues (tropospheric and stratospheric ozone chemistry), moved on to global climate change, covered energy (fossil fuel combustion, nuclear and battery technology) and included a chapter on water quality. These environmental chemistry topics were connected back to the themes of Earth System Science, particularly the interconnected nature of the Earth's spheres.

The BA environmental studies students had a much different background in science compared to the BS environmental science students. The BS students take full-year introductory sequences in biology, physical chemistry, physics and calculus in addition to upper-level courses in both environmental science and allied science fields. The BA students are required to take a quantitative reasoning class that is required for all non-science majors at DePaul, no physics, one class in ecology, the previously mentioned Earth System Science class, and environmental chemistry. The BA students were taking Chemistry of Earth Systems to fulfill the environmental chemistry requirement, so they had taken no chemistry courses since high school. But with the required courses in the environmental studies program, they did have more science exposure compared to other BA majors at DePaul. For the class used in this case study, there were four BS majors and 16 BA majors. The four BS majors were grouped together to complete their laboratory project, and the 16 BA majors were split into four groups.

These four groups and assessment instruments were used to design an experiment to test the hypothesis that HAB would promote student learning. During the first week of class, the students took the CCI to assess their baseline understanding prior to taking Chemistry of Earth Systems. The results were also used to constrain the random placement of students into the four BA lab groups; each group's mean CCI score was within one standard error of the class mean CCI score. While the BS student group scores were one standard error above the class mean, the difference was not significant ($p = 0.11$) according to a one-tailed t-test assuming an equal variance. The four BA groups developed their own laboratory projects, and two used the HAB platform and two pursued more traditional environmental chemistry projects. At the end of the class, students retook the CCI test. The hypothesis will be confirmed if the mean increase in the CCI scores for the students in the two HAB groups is significantly greater than the other two groups. The BS student group is not part of the comparison. Because attitudes towards science have also been shown to affect student learning, the per-student changes in CCI score will be correlated to the results from the CLASS-Chem. The CLASS-Chem data are assessed in two ways. First, a t-test is used to test if attitudes towards science differ significantly between HAB and traditional-project students. Second, the linear correlation between increases in CCI scores and CLASS-Chem results will be performed using HAB participation as a factor.

The design of all five of the laboratory projects was student driven. Each group developed a hypothesis and designed an experiment to test it. The first HAB group used sensors and an associated data logger from Vernier Software and Technology to measure UV A and UV B radiation and air temperature. This project complemented the project of the other HAB group, which used a UV-absorbance instrument to measure a vertical profile of ozone (O_3). Science of both tropospheric and stratospheric ozone were discussed during the first several weeks of the class, so students understood the Chapman reactions and the role of the ozone layer in absorbing different types of UV radiation. The students were also introduced to the vertical temperature structure of the atmosphere and its relationship to the ozone layer. Both HAB groups had to design and build pods to encase their experimental apparatus, overcome limitations imposed by data collection and power supplies, and do test launches of their experiments. As with many HAB projects, the experience required both understanding of the science being studied (ozone in the atmosphere) and engineering skills associated with package design.

The non-HAB projects used the same criteria and evaluation metrics as the HAB projects. The one BS group elected to measure ambient air quality on the roof of the McGowan South Environmental Science and Chemistry building at DePaul, which is located in the Lincoln Park neighborhood of the city of Chicago (1110 W Belden Ave, Chicago, IL 60614). The students measured time series of carbon dioxide (CO_2) and ozone to assess air quality, and used data from a weather station also on the roof to explore the relationship between meteorological variables and air quality. One of the traditional environmental science BA groups compared water quality upstream and downstream of the North Side Treatment Plant in Chicago, from Lake Michigan and from tap water. They measured iron, lead, chlorine, nitrates, total solids and fecal coliform. The other traditional environmental BA science group assessed indoor air quality by measuring particulate matter ($PM_{2.5}$) within several DePaul University buildings using a personal exposure monitor.

While these three groups did not participate in the development of the balloon projects, the entire class participated in the HAB launch. The HAB project students were focused on preparing their pods for the launch, so the non-HAB project students filled the balloons, set up tracking equipment and helped with the launch procedures. In addition, the whole class worked on two in-class projects to better understand HAB. The first project consisted of mathematically modeling the relationship between pressure and height and also making predictions of the HAB burst and touchdown for the upcoming class launch. The second project was based on data collected for a HAB undergraduate thesis. The data were collected during a second, simultaneous HAB launch on the same day the class projects were launched. The undergraduate thesis project uses vertical profiles of CO_2 concentration to determine the landscape-scale uptake of CO_2 by plants. In addition to evaluating these CO_2 data, the class project also looked at pressure, height and temperature data to calculate the scale height of the atmosphere for the day of the launch. While the HAB students had the most extensive exposure to the HAB experience, the non-HAB groups also gained HAB experience.

[Results from the assessments are not currently available, but they will be presented at the conference.]

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References

[1]Barbera, J., Adams, W. K., Wieman, C. E., and Perkins, K. K., “Modifying and Validating the Colorado Learning Attitudes about Science Survey for Use in Chemistry,” *Journal of Chemical Education*, 85(10), pp. 1435-1439, 2008.

[2]Grove, N., & Bretz, S. L. J., “CHEMX: An Instrument To Assess Students' Cognitive Expectations for Learning Chemistry,” *Journal of Chemistry Education*, 84(9), pp. 1524-1529, 2007.

[3]Bauer, C. F., “Beyond "Student Attitudes": Chemistry Self-Concept Inventory for Assessment of the Affective Component of Student Learning,” *Journal of Chemical Education*, 82(12), pp. 1864-1870, 2005.

[4]Bramble, J., & Workman, M., “Data-Rich Case Studies Improve Students’ Abilities to Interpret Graphs in a Large Non-Majors Course,” *Teaching Issues and Experiments in Ecology*, 5, pp. 1-23, 2007.

[5]Bowers, N., Brandon, M., & Hill, C. D., “The Use of a Knowledge Survey as an Indicator of Student Learning in an Introductory Biology Course,” *CBE—Life Sciences Education*, 4(4), pp. 311–322, 2005.

[6]Metz, A. M., *Quantitative Assessment of Student Learning in Large Undergraduate Science Classrooms: Approaches and Caveats*, in College Science Teachers Guide to Assessment, Arlington, VA: NSTA Press, 2009.

[7]Hestenes D., Wells M., & Swackhamer G., “Force Concept Inventory,” *The Physics Teacher*, 30(3), pp. 141-166, 1992.

[8]Mulford, D. R., & Robinson, W. R., “An Inventory for Alternate Conceptions among First-Semester General Chemistry Students,” *Journal of Chemical Education*, 79(6), pp. 739−744, 2002.

[9]Bardar, E. M, Prather, E. E., Slater, T. F., & Brecher, K., “Development and Validation of the Light and Spectroscopy Concept Inventory,” *Astronomy Education Review*, 5(2), pp. 103, 2007.

[10]Keller, J., “Development of a Concept Inventory Addressing Students’ Beliefs and Reasoning Difficulties Regarding the Greenhouse Effect,” Doctoral Dissertation, University of Arizona, 2006.

[11]Hufnagel, B., “Development of the Astronomy Diagnostic Test,” *Astronomy Education Review*, 1(1), pp. 47–51, 2002.

[12]Snyder, A., Romines, E., & Dodge, R., “New Heights High Altitude Balloon Research Program,” *ASEE Conference*, Austin Texas, 2009.

[13]Perkins, K. K., Gratny, M. M., Adams, W. K., Finkelstein, N. D., & Wieman, C. E., “Towards Characterizing the Relationship Between Students’ Interest in and their Beliefs about Physics,” *Proceedings of the 2005 Physics Education Research Conference*, 2005.

[14]van der Hoeven Kraft, K. J., Srogi, L., Husman, J., Semken, S., & Fuhrman, M., “Engaging Students to Learn Through the Affective Domain: A new Framework for Teaching in the Geosciences,” *Journal of Geoscience Education*, 59, pp. 71-84, 2011.

[15]Gungor, A., Eryilmaz, A., & Fakioglu, T., “The Relationship of Freshmen's Physics Achievement and their Related Affective Characteristics,” *Journal of Research in Science Teaching*, 44(8), pp. 1036-1056, 2007.