Bridging the conceptual divide between theoretical and applied environmental chemistry

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PROJECT DESCRIPTION

Motivation

Over the past thirty years, geological and environmental science research (e.g., hydrology, ecology, paleoceanography) have utilized stable isotope ratios in an increasing trend in all aspects of research—to trace active processes in the environment such as biomineralization, to fingerprint sources or identify the origin of samples, and to reconstruct past-environments to name a few. In other fields, the potential for isotope studies are being explored and becoming more routine. For example, the doping scandal in professional cycling after the 2006 Tour de France used carbon isotopes to differentiate between naturally produced testosterone and that from an external source (Kotz et al., 2008). In Africa, $\delta^{18}O$ is used to determine the origin of confiscated samples of ivory obtained from poachers to determine which populations of elephants were impacted.

Students are presently exposed to isotopes and their use in introductory and upper division courses in chemistry, geology, and biology. However, few undergraduate students actually understand how to measure isotope ratios or interpret results. We hypothesize that modern undergraduate education demands the exposure of students to the use of relevant instrumentation to bridge the conceptual divide between theoretical and applied environmental chemistry. The proposed project will bring a relatively simple, but never-the-less powerful instrument for precisely analyzing isotope ratios into the classroom (Fig. 1) and present students with the opportunity to ask questions, formulate hypotheses, generate data, and then analyze and interpret complex data sets. In short, the students will learn science by doing science, in addition to more traditional forms of classroom lectures and readings. This proposal will assess what impact, if any, a research-based approach to teaching has on students' overall approaches to learning and student perceptions of course quality.

Figure 1. Example of water isotope analyzer in an agricultural field near Hanoi, Vietnam and in the 'classroom' in Beijing, China (photos provided to Griffith as per her request by Scott Moore at Picarro).

Both Griffith and Ortiz have several examples of the joy of discovery of hands on research activities with undergraduate and high school students doing independent investigations in their labs. Lindsey Brenizer (undergraduate student in Ortiz' lab) remarked "*This was the absolute BEST part of my year so far (well, second to my engagement…). Thank you so much for introducing me to all the adventure!!!*" Allison Reynolds (high school student in Griffith's lab) remarked of her independent investigation through the post-secondary enrollment option program (PSEOP), "*My favorite part was working on/with the SEM to see the samples and take pictures. The coccoliths were all different shapes and sizes…*" While students in Griffith's Hydrogeochemistry class (Spring 2010) rated the course overall as 'fair' (Table 1) during the first semester that it was taught, when evaluating the use of water quality probes for hands on activities all the students agreed that their use enhanced their ability to a) understand their major study and b) analyze data. Most of the students (10 out of 14) also would like to see the probes used in other classes that study environmental science. These probes were newly acquired in part using funds from a Kent State University Teaching Council grant to Griffith. Their success in the class prompted us in part to expand the use of instrumentation of this type through this proposal.

While this is anecdotal evidence, utilizing undergraduate research as a means to improve student learning has long been an integral part of a university education. However, recent studies (Adhikari & Nolan, 2002; Badley, 2002; Bauer & Bennet, 2003; Baldwin, 2005; Luck, 2008) have questioned how, and in what ways, undergraduate research specifically adds to student learning. This project proposes to test its incorporation with the following specific goals.

The ***goals*** for this project are to:

(1) develop and modify learning outcomes in two upper division science courses that apply fundamental geologic and geochemical concepts to complex problems,
(2) enhance and deepen student learning outcomes through active teaching strategies using geochemical data (stable isotopes),
(3) enrich the education of future scientists and members of our community, and
(4) provide an example for developing multi-modal teaching modules to enhance student learning outcomes at Kent State and within the academic community.

We hypothesize that developing and incorporating student-led investigations in the field, laboratory, and classroom using stable isotope data will engage students and facilitate a deeper understanding of *"modeling and predicting the geochemical processes that control the chemistry of natural waters and their evolution in the hydrological cycle"* (learning outcome targeted in Hydrogeochemistry) and *"discussing and describing the role of the ocean in the evolution of Earth's climate from a systems perspective"* (learning outcome targeted in Paleoceanography). We will test this hypothesis using both qualitative and quantitative measures as outlined in our project assessment led by P.I. David M. Dees. Dees will serve as our independent assessor in this study. He is not a geoscientist (like Griffith and Ortiz), but an associate professor of Cultural Foundations in the College of Education, Health, and Human Services and a Senior Faculty Associate at the Kent State University Faculty Professional Development Center with expertise in student learning, university teaching, and assessment.

Changes from 2010 proposal—The revised proposal explains in greater detail student learning outcomes and assessment, which has increased the role of Dees as an independent assessor for the project. We also decided to target two upper-division courses and one of each of their overall student learning outcomes. This has allowed us to demonstrate how we will proceed with incorporating the new technology into the classroom and test whether or not its inclusion in a research-based approach to teaching changes students' achievement of specific learning outcomes compared to previous results without incorporation of the technology.

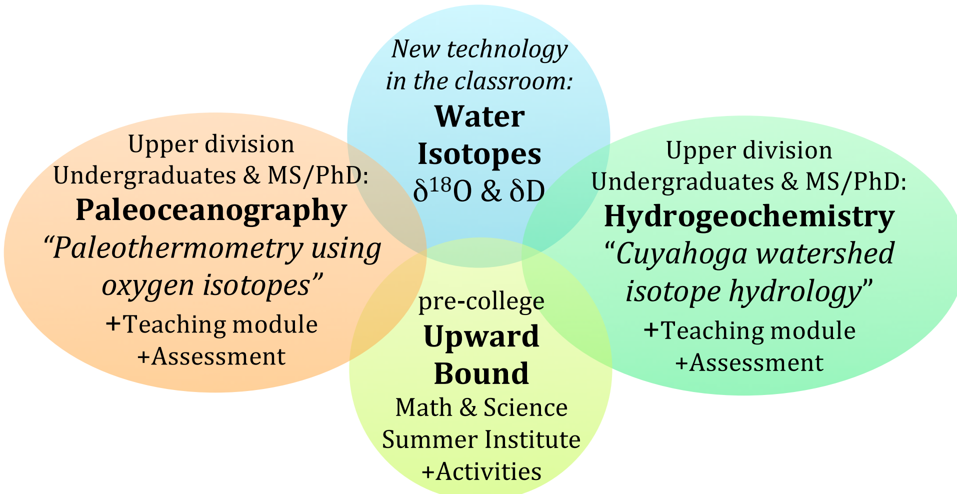

Figure 2. Diagram of proposed project components and relationships.

PROJECT OUTLINE

Two upper division elective courses will be targeted in this proposal (Fig. 2), related to the scientific specialties and core intellectual passion of the research groups of Griffith and Ortiz. The courses, *Hydrogeochemistry* and *Paleoceanography*, have been taught at least one time previously with potential for enhanced learning outcomes (see Table 1). Various teaching strategies have been employed (e.g., laboratory experiments, group research projects, in-class derivations, and oral and poster presentations), but a thorough and academic analysis focused on student learning outcomes has not been attempted. Prior to this proposal 'student learning outcomes' were not constructed for *Hydrogeochemistry*, nor are they standard in course or program level descriptions in the science departments at Kent State University. Ortiz previously outlined overall expected outcomes for *Paleoceanography* (see brief course descriptions in the following section).

Table 1. Overview of pre-project course demographics and learning benchmarks.

Course	Student enrollment	Course evaluations
Hydrogeochemistry* (Griffith)	Spring 2010 Enrollment of 15 with 5 undergrads (2 ecology) 8 M.S. and 2 Ph.D. students	Overall learning experience: 2.4 ±1.2 (excellent= 5.0)
Paleoceanography (Ortiz)	Spring 2006, Spring 2009, Fall 2010 Enrollment of 6, 5, 13 with generally 1-2 undergrads and a 4:1 ratio of M.S.:Ph.D. students	Overall learning experience: 4.0 ±1.1, 4.0±0.7, and 3.9 ±1.3 (excellent = 5.0)

**indicates inclusion in the new Environmental Geology concentration*

The first step in our project was to construct student learning outcomes for the two chosen courses. Learning outcomes help both faculty and students identify important course elements as well as monitor student success throughout course learning experiences. As Maki (2004) notes, "A learning outcome statement describes what students should be able to demonstrate, represent, or produce based on their learning histories" (p. 60). Following this challenge the researchers have constructed learning outcome statements that ***1***) have clear expectations, ***2***) are meaningful, ***3***) are verifiable, and ***4***) include student actions.

Next, a single learning outcome will be chosen and serve as the driving force for developing and assessing multi-modal learning activities that focus on bridging the conceptual gap between theoretical and applied chemistry using stable isotope geochemistry specifically. The activities will then be constructed, tested, and modified before being incorporated as a teaching module within the coursework. This will occur at least one semester prior to teaching of the selected courses. ***Finally*** the activities will be incorporated into the course and assessed both qualitatively and quantitatively following the assessment plan outlined in the following section.

Brief course descriptions

Hydrogeochemistry— The course catalog description is: 'Processes and evolution of the chemical composition of water in the natural hydrologic cycle. Methods of hydrochemical interpretation applied to ground water and pollution problems.' Griffith has taught this course once in Spring 2010. The format of the course has been two 1¼ hour blocks per week for lectures, in-class worked problems, discussion of case studies and student presentations. Incorporation of hands-on group laboratory experiments within this time block was found to be ineffective as students did not have sufficient time to satisfactorily complete the reflections/interpretations in-class with their peers. Incorporating laboratory exercises (first half of semester) and a group research project at the Kent State River and the Aquatic Ecology Research Facility (AERF) wetlands on campus (second half of semester) into the course in Spring 2010 led to much discontent as evidenced in the student course evaluations (Table 1). A modified class schedule will be discussed along with development of a new learning module in the following sections.

Paleoceanography— From Ortiz' class website, the overall expected outcome for Paleoceanography: 'In this class we will explore how the ocean fits into the Earth system and learn how the ocean and Earth system have changed in response to internal and external forcing.' Ortiz has taught the class three times since Spring 2006. The course consists of two 1¼ hour blocks per week used for a flexible mix of lecture, group activities, and student presentation. The class incorporates a term project and field trip to study Cambrian to Devonian paleoceanographic strata preserved in rock cores at the Ohio Geologic Survey's H.R. Collins Lab, located just two hours from Kent State University. Graduate students are encouraged to incorporate their research into the class project where appropriate and with permission of the instructor.

Constructing and targeting student learning outcomes

The following student learning outcomes were constructed for each course with the first outcome listed for each class as the targeted student learning outcome. Note that this is our first attempt in constructing learning outcomes and these will likely be modified during the course of the proposed project.

Griffith's **Hydrogeochemistry** Student Learning Outcomes:

1. Using their understanding of chemical thermodynamics and kinetics, students will be able to model and predict the geochemical processes that control the chemistry of natural waters and their evolution in the hydrological cycle.
2. Through the creation and completion of a research project, students will apply and model the key principles of the scientific method.
3. Students will collect, analyze and evaluate data from student -generated research projects.
4. Students will be able to explain and discuss geochemical data and their significance with their peers and other scientists.

The first learning outcome was chosen as the targeted outcome for this proposal because it is the most difficult for students to master and gain a deeper understanding, but it is *the* essential content of the course. Many students are intimidated by math and chemistry that is key to master in order to fulfill this outcome. These techniques are not intrinsically visual or tactile, like many aspects of geology, making them oftentimes difficult for geoscientists. However, students are quite motivated to complete work required of them, and will practice solving chemical and mathematical equations if they see the relevance and meaning in the activity (Bransford, Brown, Cocking, 2000; Weimer, 2002; Willingham & Lloyd, 2007). A teaching module which reconstructs the hydrology of a local (familiar) watershed using water isotopes (δD and $\delta^{18}O$) will allow the students to create a 'concrete' model of the geochemical and hydrological processes in order to gain an intuition of how these processes control the chemistry of the natural water in a predictable and measurable way (Table 2). As noted throughout learning theory (Zull, 2002, 2006; Sousa, 2006; Willingham, 2009) allowing students to visualize and create concrete images of complex concepts increases understanding, retention and transfer of learning.

Ortiz' **Paleoceanography** Student Learning Outcomes:

1. Students will be able to discuss and describe the role of the ocean in the evolution of Earth's climate from a systems perspective.
2. Students will apraise the methods that paleoceanographers use to infer age in the geologic past.
3. Using data and modeling results from the literature, students will interpret paleoceanographic changes through time and its impact on climate.
4. Students will use their knowledge of paleoceanographic history to apply and predict how potential oceanographic trends will likely impact future climate.

The first learning outcome was selected because it expands and facilitates the students' deeper learning by introducing the earth system science perspective and the approaches used to study change in ocean history. It also builds off of the learning outcomes selected for the Hydrogeochemistry class. The learning outcomes for the proposed teaching module will systematically present the case that our understanding of how a modern isotope system operates enables us to build a proxy that can be used to infer changes in the state of the climate system through time. We select oxygen isotopes as our model system to study (Table 2), because the systematics are straightforward and the body of work conducted in this area is extremely vast.

Table 2. Overview of targeted courses and summary of proposed teaching module.

Course	Student population	Teaching module	Instructional time (hours)
Hydrogeochemistry (Griffith)	Upper division undergraduates, MS/PhD students	Cuyahoga watershed isotope hydrology	7 (2x2½hr and 2x1hr class periods)
Paleoceanography (Ortiz)	Upper division undergraduates, MS/PhD students	Paleothermometry using oxygen isotopes	4 (2 lectures and in class activities)

Building a teaching module

I. Cuyahoga Watershed Isotope hydrology

Learning outcomes specific to this teaching module

- Students will create a concept map which traces the global hydrologic cycle using stable water isotopes ($\delta^{18}O$ and δD) using fundamental principles such as isotopic fractionation, equilibrium and kinetic processes.
- Students will create a concept map which traces the local hydrologic cycle in the Cuyahoga watershed using stable water isotopes ($\delta^{18}O$ and δD).
- Students will use their concept map to create testable hypotheses surrounding hydrologic processes within the Cuyahoga watershed.

It should first be noted that Griffith has modified the existing class from two 1¼ hour lectures to one 2½ hour lecture/lab and one 50 minute lecture to begin Fall 2011. This modified schedule is desirable to allow for more involved laboratory activities and local field trips to collect and analyze water chemistry *in situ* and back at the analytical facilities in the department. The above learning module will likely involve two weeks of instruction (2 x 2½ hour labs and 2 x 50 minute lectures). After a lecture on fundamental principles of stable isotope geochemistry, the class will be divided into 3-person groups to construct concept maps of stable water isotopes in the global hydrologic cycle (which has been introduced previously in the class). Following resources at Science Education Resource Center (SERC), concept maps can test the students' "ability to draw reasonable inferences from observations, synthesize and integrate information and ideas, and learn concepts and theories". Because of the complex relationships, this is an ideal form of assessment which allows students to visualize these interdependent processes.

For homework, students will be assigned the task of creating a concept map which traces water isotopes in the local hydrologic cycle in the Cuyahoga watershed. These will be shared in the following class period and testable hypotheses will be constructed from their concept maps, such as predicting relationships between groundwater, different types of precipitation, and riverine water. We will also review how to take a water sample for isotopic analysis. The following class period, students will bring in samples that they collected over the weekend (along with archived samples previously collected by Griffith and others) to measure on the isotope analyzer and test their hypotheses. The last class period will synthesize all the data and compare to previously published data from the region and similar watersheds.

II. Oxygen Isotope Paleothermometry

Learning outcomes specific to this teaching module

- Students will be able to interpret how the global oxygen isotope signal is imprinted by the atmospheric processes of evaporation and precipitation.
- Students will be able to illustrate how oxygen isotopes can be used to trace changes in modern ocean circulation.
- Students will be able to discuss how oxygen isotopes preserved in fossils can be used to calculate: geologic age, paleotemperature, ice volume, and when used in conjunction with another proxy, information about paleosalinity.

To fully appreciate the nuanced information that can be extracted from oxygen isotopes of biogenic carbonates requires students to master several threads of inquiry. They must understand the basics of isotope fractionation, the specific physical processes of isotope fractionation involved in generating natural isotopic gradients in the physical system, the spatial and temporal patterns evolving from these fractionation processes, and the biophysical mechanisms by which these proxies are recorded in the fossil record. This provides the basis of information needed to employ oxygen isotopes first as informal stratigraphic (geologic age) proxies to differentiate glacial from interglacial and stadial from interstadial events depending on the sedimentation rate of the core site employed. It is one thing to learn this material from a book. It is quite another to design an experiment and operate an instrument to generate 'new' data. To help students understand these methods, they will learn how to measure $\delta^{18}O$ of different seawater samples that have evaporated to varying degrees using the Piccaro isotope analyzer.

A more quantitative and in depth look at the system allows paleoceanographers to differentiate the relative importance of ice volume and temperature recorded in the shells of foraminifera, and finally by integrating information from another paleotemperature proxy (Mg/Ca), it is possible to extract information about paleosalinity.

This framework suggests two different teaching activities appropriate to help students master the material. To teach the systematics and conceptual framework, we will employ an extended jigsaw approach in which the class is divided into groups, and each group is given teaching resources and publications from the primary literature that focus on one aspect of the problem (Table 3). Ortiz has used this approach successfully in his Sedimentology and Stratigraphy class where students work on developing on extensive field guide prior to a weekend trip to West Virginia to study Missippian-Pennslyvania strata.

Table 3. *Jigsaw group topics*

1.	Isotope fractionation and Rayleigh distillation on glacial-interglacial timescales
2.	Modern geographic distribution of oxygen isotopes in the ocean using data and models
3.	Paleotemperature equations calibrated by field work, core tops, and lab cultures
4.	Marine Isotope Stratigraphy
5.	Paleosalinity estimation

Students will be assigned into groups during one class period and given an explanation of the assignment and background information. Each group will then have a one week period to meet and discuss the material and develop a presentation to explain their aspect of the problem to the class during a future class meeting period. Each group will then present their "research" findings to the class, followed by a discussion session lead by the instructor centered around analysis of a data set extracted from a short research paper that the students did not use in their research. Each group of "experts" will be asked to address some aspect of the work from the paper so that the class as a whole will be able to comment in depth about the new piece of literature under discussion. From this exercise, students should gain insights into how oxygen isotopes are employed in paleoceanography and gain confidence in their ability to master complex material from the primary literature. The exercise also models how to "chunk" a complex problem into smaller, manageable parts.

The second teaching activity will be focused on application of the new knowledge that the students had mastered for quantitative analysis of oxygen isotope data. Students would be given data sets from the literature from which they would calculate paleotemperatures in Excel, after making appropriate assumptions regarding the value of $\delta^{18}O$ of seawater, and the magnitude of the ice volume effect at different times in the past. Part of the assignment would be for them to incorporate independent paleotemperature estimates to infer paleosalinity after inverting the oxygen isotope equation. An important part of this assignment would be to conduct an error analysis in which they compare various paleotemperature equations and propagate the various sources of error during the paleosalinity estimate. Ortiz can provide data sets from his dissertation work and from current NSF projects in which he is conducting these types of analysis. This will help to bring "active research" into the classroom to help get students excited about the analytical methods.

Community outreach

We will develop similar versions of our teaching modules and learning activities for high school students to be included in the Pre-College/TRiO Upward Bound Math & Science Summer Institute in the Division of Diversity, Equity & Inclusion at Kent State University (see letter of support). The Math & Science Summer Institute is a federally funded TRiO program with a long history at Kent, established as a university and community partnership ten years ago. The program was established to "to provide students who are first-generation college and meet income guidelines the preparation, support, and opportunities to successfully enter into postsecondary education in mathematics, science, and/or technology." (http://www.kent.edu/diversity/pipeline/precollege/upmathscience.cfm) "TRiO programs help students overcome, class, social, academic, and cultural barriers to higher education." Students attending the Math & Science Summer Institute reside in dormitories on campus and attend the 6 week program covering a full range of activities from classes in math and science, field trips, and social and cultural activities. To connect with the community at the Salem campus, where Dees is located, undergraduate students interested in STEM majors will participate as mentors for the Upward Bound students, thus extending our community outreach to students from rural Appalachia.

Graduate students in our department (one in Griffith's group and three in Ortiz' group) have been chosen to lead these students in learning about the geosciences using classrooms in our building this summer and in the past. We will take advantage of this established and extremely successful program to expose the high school students to applications of chemical data in hydrogeochemistry and paleoceanography. For many high school students and teachers a lack of a deep understanding of instrumental theory used for collecting the geochemical data will not limit their appreciation for analyzing the data. This step is important for reaching lower division and nontraditional students who might not otherwise be drawn to the sciences, but are attracted by the very nature of the geosciences which have 'a concreteness, a relevance and an immediacy' (Riggs & Alexander, 2007).

Figure 3. Photos of high school students (first three photos) in the lab and working on the department's scanning electron microscope this past fall. Far right, 8th grade student doing Pb analyses using a Hach® colorimeter of water samples for her science fair project (January 2011) which was selected to go to state competition.

Both PIs can be viewed as role models for such under-represented groups in the sciences (Griffith being a female and Ortiz an ethnic minority). Furthermore, the new research initiatives proposed in this project will provide the foundation and initial results required for a recently hired female assistant professor (Griffith) to propose future research and develop new projects in hydrogeochemistry at KSU and specifically for educational plans in a NSF CAREER proposal (to be submitted summer 2012). For example, as we acquire new isotope data, we envision incorporating these preliminary results in research proposals and they will serve as the impetus for undergraduate honors projects and independent studies and graduate theses. Additionally, if we acquire and incorporate the new water isotope analyzer, we envision the addition of an inlet system to allow analysis of carbonates through acid digestion to release CO_2 followed by oxygen exchange with H_2O. Likewise, we would seek acquisition of a Picarro *i*TOC-CRDS $\delta^{13}C$ system for analyzing carbon isotope ratios in soils, sediments, and plant materials for studies in hydrogeology, limnology, paleoceanography, and marine and freshwater ecosystems.

Project assessment

Several studies have suggested that the university educational environment influences how and what students learn (Trigwell, Prosser, Waterhouse, 1999; Entwistle, McCune, Hounsell, 2002; Wilson & Fowler, 2005; Nijhuis, Segers, Gijselaers, 2008). This project will utilize both qualitative and quantitative assessment measures to identify changes in student learning around specific learning outcomes (refer to Table 4 Assessment Map at the end of the project description). Additionally, this study will also assess the effect, if any, that this project had on students' overall approaches to learning. Finally, student perceptions of course quality will be assessed in an attempt to identify the impact of a research-based approach.

Quantitative Measures

Prior knowledge assessment is a critical element to understanding changes in students' achievement of specific learning outcomes (Kolb, 2002; Zull, 2002, 2006; Jensen, 2008 Glisczinski, 2011). In order to quantify changes in student learning, a pre-test that focuses on students' current conceptual understanding of critical course concepts will be administered in each course. The conceptual survey in Paleoceanography will focus on content related to students' understanding of the earth system science perspective and the approaches used in the field to study changes in ocean history. The conceptual survey in Hydrogeochemistry will examine students' knowledge of chemical thermodynamics and kinetics. At the end of the semester a similar post-test survey will be administered to identify changes in their conceptual understanding of these critical concepts.

A second element of this study is to identify how, and in what ways, creating and applying knowledge influences students' overall approach to learning. Several theorists (Entwistle, 2001; Bain, 2004; Biggs & Tang, 2007) have identified that students utilize one of three (deep, surface, or strategic) approaches towards their learning. Deep learners focus on understanding the underlying principles of the material they are studying. Surface learners, on the other hand, focus on memorizing and/or following prescribed procedures rather than thinking for themselves. Strategic learners, like surface learners, only focus on the superficial understanding of the material and are mostly concerned with doing what they think satisfies the instructor's expectations. It has become clear from this research that the structure and approach of the classroom influences the approaches utilized by students. This study will examine whether a research-focused, application-oriented approach to geoscience changes students' attitudes and/or approaches towards learning.

The Learning and Studying Questionnaire (LSQ) and the Experiences of Teaching and Learning Questionnaire (ETLQ) developed by the *Enhancing Teaching-Learning Environments in Undergraduate Courses Research Program* (http://www.etl.tla.ed.ac.uk/index.html) were designed to identify the influence that the environment has on students' approaches to learning. The first questionnaire (LSQ) will be administered at the beginning of the semester and will identify students' intended approach (deep, surface, or strategic) towards learning in each of the selected course sections. The second measure (ETLQ) will be given towards the end of the learning module in which the students utilized the research equipment. This questionnaire measures how students actually approached learning during this particular segment of the course. Comparisons between the two measures can be used to identify the influence that the learning module had on students' approaches towards learning. Typically used throughout Europe and Australia, these measures provide tangible insight into the effects that course design has on student learning.

Qualitative Measures

A qualitative assessment of student learning will be achieved through post-semester focus groups. In both courses, randomly selected students will be invited to participate in these group conversations. An adaptation of the Small Group Instructional Diagnosis (Coffman, 1991; Millis, 1999) technique will be utilized to access student feedback on how they perceived a change in their learning through the use of the research equipment. These focus groups will consist of at least 5 students from each course section. A thematic analysis, with member checking, will be conducted by one of the P.I.'s (Dees) to identify any perceived significant changes in student learning.

Combined Qualitative and Quantitative Measures

The Student Summary of Instruction (SSI) consists of both Likert-type and open ended questions that are designed to measure student perceptions of their learning experiences at Kent State University. Although not a requirement, every student at Kent State University is provided with class time towards the end of the semester to complete these evaluations without the faculty member present. Quantitative comparisons will be made between the SSI findings from these selected course sections and representative campus norms. Both quantitative (Likert-type questions) and qualitative (open-ended questions) assessments will be made between course sections that utilized the isotope analyzer and previous sections that did not have this opportunity. Cross-comparisons between student responses will provide insight into any perceived value students may have placed on utilizing a more research-oriented approach to these specific courses.

Another useful measure in this proposed study will be the comparisons made between previous and current course assessments. Exam, quiz, and case study questions from previous course sections will be compared with current student responses. Utilizing a rubric created by the course professors, the independent assessor (Dees), along with a trained graduate assistant, will analyze specific student answers that were designed to focus on the primary learning outcomes. Due to the nature of these assignments, both quantitative and qualitative analyses will be required to identify any significant differences between the two groups.

This proposed study combines a variety of robust qualitative and quantitative assessment measures. These diverse assessments will provide insight into a) achievement of the student learning outcomes, b) any changes in students' approaches to learning, and c) student attitudes toward their learning. Balancing between both qualitative and quantitative measures in each of critical assessment areas, the researchers will be able to identify how and in what ways the use of this research equipment influenced student achievement of the primary learning outcomes and their overall perception of course quality.

Dissemination of results

One or two manuscripts will be submitted to a peer-reviewed journal such as the *Journal of Geoscience Education* outlining our project's successes (and failures) and best practices to archive our results, initiate discussion surrounding student-led inquiry and active learning in the field of geoscience education, and provide a reference for future educators. Results will include the quantitative and qualitative assessment of the impact, if any, of exposure to "cutting edge" geochemical data on student learning in the sciences.

Other possible outlets for the educational component of this research include the *Journal on Excellence in College Teaching*, *International Journal for Teaching and Learning in Higher Education*, and *Assessment and Evaluation in Higher Education*.

Publishable scientific research results will be presented at regional and international scientific conferences as the opportunity presents itself and submitted to peer-reviewed journals such as *Environmental Earth Sciences, Chemical Geology, Isotopes in Environmental and Health Sciences, Ecology, Geochimica et Cosmochimica Acta,* and *Hydrogeology Journal*. Appropriate isotope analyses will be submitted to be included in an existing global isotopic data such as the IAEA Isotope Hydrology Information System (ISOHIS).

MERIT REVIEW CRITERIA

Intellectual merit

The proposed project will expand on the existing body of research on incorporating new technology in undergraduate STEM education and its potential transformative effects on developing deeper knowledge through experiential learning. Specifically it will develop materials that will enhance student learning outcomes at our university, in the community, and in the future, other institutions. Educators from other institutions and in the community will have access to our teaching materials through the online resources through the Science Education Resource Center (SERC) website. Our project will also serve as a model for other institutions regarding how to develop and incorporate teaching modules targeted at student learning outcomes to enhance deeper learning and higher analytical and statistical skills through primarily student-led research activities in the classroom. An independent assessment will analyze the results using both qualitative and quantitative measures to identify changes in student learning around specific learning outcomes, and assess the effect, if any, that this project had on students' overall approaches to learning. Student perceptions of course quality will also be assessed in an attempt to identify the impact of a research-based approach.

Broader impacts

To summarize, the broader impacts described in this proposal include (1) interacting with the local community through teaching activities incorporated in the Upward Bound Math & Science Summer Institute at Kent State for high school students and inclusion of students from our Salem campus in rural Appalachia, (2) sharing our experiences with the greater community through dissemination of education and research results, and (3) serving as an example for developing multi-modal teaching modules to enhance student learning outcomes at Kent State and within the academic community. Collectively, all of these components will serve to enrich the education of future scientists and members of our community. We will target and support under-represented (minorities and women) and low-income students. Furthermore, the applications developed in this proposal will provide the foundation and initial results required for a recently hired female assistant professor (Griffith) to propose future research, promote excellence in teaching (see letter of support from departmental chair), and develop new projects in hydrogeochemistry at Kent State.

Table 4. Project Assessment Map

Within Course Assessment

Type of Assessment	Assessment Measures	Assessment Approach	Timing
Learning and Studying Questionnaire (LSQ) with Experiences of Teaching and Learning Questionnaire (ETLQ)	This will assess the impact that applying research methods has on students' approaches to learning (deep, surface, or strategic).	Quantitative	LSQ is given early in the semester. The ETLQ should be given towards the end of the learning module that utilizes the selected research equipment.
Pre- and Post-Conceptual Test	This will assess a change, if any, in students understanding of critical concepts such as a) the earth system science perspective, b) approaches used to study changes in ocean history, c) chemical thermodynamics, and d) kinetics. These concepts are fundamental to the achieving the primary course learning outcomes.	Quantitative	Pre-test will be given early in the semester. Post-test questions will be incorporated into the final course examinations, projects, and/or papers.
Adapted Small Group Instructional Diagnosis (SGID)	This will assess students' perceptions of the influence of the applied research perspective.	Qualitative	The adapted SGID will be conducted at least one month after the conclusion of the semester.

Between Course Assessment

Type of Assessment	Assessment Measures	Assessment Approach	Timing
Student Survey of Instruction (SSI)	This measures students' perceptions of the course, their own learning, and faculty quality. Comparisons of SSI's will be made between selected course sections that have utilized the applied research approach and those previous sections that were more theoretical.	Quantitative and Qualitative	This is always given during the last two weeks of a semester.
Course Assessment Comparisons	This will compare and contrast students' exam, quiz and/or case study answers from applied research course sections with previous offerings. Questions will be chosen that reflect important elements of the primary learning outcomes for each course.	Quantitative and Qualitative	This will focus on exam/quiz/case study questions given throughout the semester in each of the course sections. Analysis will be conducted at the end of the course.

Prior Results

Results from most relevant NSF grants (Griffith)

Griffith recently was awarded NSF grant EAR-1053312 (*Collaborative Research: Stable strontium isotope ratios (88/86Sr) in abiotic and microbially mediate barite*. $142,200. 3/1/11-2/28/13) funded by the Geobiology and Low-Temperature Geochemistry program in collaboration with Dr. Howie Scher at the University of South Carolina NSF grant EAR-1053474. One female Ph.D. student will be funded on this proposal (starting end of May 2011) with several undergraduate students volunteering to assist in field preparations and laboratory analyses. As of May 2011, no publications or presentation have resulted.

Griffith also worked as a graduate student funded by a NSF Graduate Research Fellowship (awarded 2003) to study the stable Ca-isotopic composition of barite and biogenically precipitated carbonate to understand changes in the biogeochemical cycling of Ca in the present and the past. The research was funded by NSF grant OCE-0753275 (*CAREER: A Research and Educational Plan in Global Biogeochemical Cycles: Seawater Calcium Isotopes and Carbonate Depositional History*. PI: A. Paytan, $674,339). Griffith's thesis work and contribution to this project involved mentoring students in the lab (Gray, Erhardt) and a visiting high school teacher (summer 2005) and resulted in several publications listed below:

Griffith, E. M., A. Paytan, K. Caldeira, T. D. Bullen and E. Thomas (2008) A dynamic marine calcium cycle during the past 28 million years. *Science*, **322**, 1671-1674.

Griffith, E. M., E. A. Schauble, T. D. Bullen and A. Paytan (2008) Characterization of calcium isotopes in natural and synthetic barite. *Geochimica et Cosmochimica Acta*, **72**, 5641-5658.

Griffith, E. M., A. Paytan, R. Kozdan, A. Eisenhauer and A. C. Ravelo (2008) Influences on the fractionation of calcium isotopes in planktonic foraminifera. *Earth and Planetary Science Letters*, **268**, 124-136.

Results from most relevant NSF grants (Ortiz)

Ortiz has made a considerable impact on Earth Science Education in Northeast Ohio at the high school, undergraduate, and graduate levels. As one of the co-PI of an NSF-funded GK-12 program, Ortiz interacted with dozens of teachers and over 10,000 high school students per year in Stark County, OH for five years (http://neogeo.kent.edu/). The PI was one of two faculty members responsible for developing and implementing a field-based workshop for in service teachers.

Ortiz has also had several NSF-funded research projects, most recently employing diffuse spectral reflectance measurements by visible (VIS) derivative spectroscopy to reconstruct changes in ocean circulation and productivity related to climatic events among other factors. Research was/is funded by NSF grants EAR-09021753 (*Collaborative Research: Spatial and temporal patterns of drought in Western North America during the Holocene*. $235,416. 09/01/09-08/31/2011), OCE-0213646 (*Collaborative Research: A High resolution record of Productivity and/or ventilation of the Northeast Pacific from Soledad Basin, Baja California*. $150,918. 09/01/02-08/31/07) and related ARC-0612384 (*Collaborative Research: Investigating Holocene paleoclimate in the western Arctic Ocean using high-resolution Alaskan Margin records.* $107,508. 10/01/06- 09/30/09). Research funded by these three projects has to date resulted in 12 publications (including those listed below) and over 20 published abstracts. Broader Impacts associated with the recent Science paper include a *Science* Perspective piece

(Keeling, *Science*, 2007) and national and international interest in press releases, web articles and NPR radio spots.

In addition to publications and presentations in international journals and at meetings, research results from these projects are incorporated as examples into lectures for the PI's *Oceanography* class of ~175 students, his upper division seminars in *Paleoceanography* and *Environmental Core and Well Logging* of 10-20 undergraduate/graduate students, and as laboratory exercises for his upper division *Stratigraphy* class with annual enrollment of 10-20 students. Ortiz has employed many undergraduates from KSU in research in his lab and in the field (including participation on oceanographic expeditions) several of whom have since enrolled in Geology or Earth Science graduate programs or continued in the field working as government researchers or in industry.

Nelson, D.B., Abbott, M.B., Steinman, B., Polissar, P.J. Stansell, N.D., **Ortiz, J.D.,** Rosenmeier, M.F., Finney, B.P., and Riedel, J., 2011, Drought variability in the Pacific Northwest from a 6,000-yr lake sediment record, *PNAS*,doi/10.1073/pnas.1009194108.

Yurco, L., **Ortiz, J.D.,** Polyak, L., and Darby, D., 2010 Reflectance-based clay mineral cycles in Quaternary sediments from the Northwind Ridge: implications for glacial-interglacial sedimentation patterns in the Arctic Ocean, *Polar Research*, DOI: 10.1111/j.1751-8369.2010.00160.x.

Marchitto, T.M., Muscheler, R., **Ortiz, J.D.,** Carriquiry, J., and van Geen, A., 2010, Dynamical response of the tropical Pacific Ocean to solar forcing during the early Holocene, *Science*, **330**, 1378-1381, DOI: 10.1126/science.1194887

Ortiz, J.D., Polyak, L., Grebmeier, J. M., Darby, D.A. Eberl, D.D., Naidu, S. and Nof, D., 2009, Provenance of Holocene sediment on the Chukchi-Alaskan margin based on combined diffuse spectral reflectance and quantitative X-Ray Diffraction analysis. *Global and Planetary Change*, **68**, 73-84.

Darby, D.A., **Ortiz, J.D.,** Polyak, L., Lund, S., Jakobsson M., and Woodgate, R.A., 2009, The role of currents and sea ice in both slowly deposited central Arctic and rapidly deposited Chukchi-Alaskan margin sediments. *Global and Planetary Change,* **68**, 58-72 .

Adler, R.E., Polyak, L., **Ortiz, J.D.,** Kaufman, D.S., Channell, J.E.T., Xuan, C., Grottoli, A.G., Sellen E., and Crawford, K.A., 2009, Sediment record from the western Arctic Ocean with an improved Late Quaternary age resolution: HOTRAX core HLY0503-8JPC, Mendeleev Ridge. *Global and Planetary Change*, **68**, 18-29.

Polyak, L., Bischof, J., **Ortiz, J.D.,** Darby, D.A., Channell, J.E.T., Xuan, C., **.,** Kaufman, D.S., Løvlie, R., Schneider, D.A., Eberl, D.D., Adler, R.E., and Council, E.A., 2009, Late Quaternary stratigraphy and sedimentation patterns in the western Arctic Ocean. *Global and Planetary Change*, **68**, 5-17.

Brachfeld, S., Barletta, F., St-Onge, G., Darby D.A., and **Ortiz, J.D.,** 2009, Detrital and diagenetic magnetic signatures of sediment supply and water column stratification in Holocene sedimentary records from the eastern Chukchi Sea. *Global and Planetary Change*, **68**, 100-114.

Marchitto, T.M., Lehman, S. J., **Ortiz, J.D.,** Fluckinger, J., and van Geen, A., 2007, Marine radiocarbon evidence for the mechanism of deglacial atmospheric CO_2 rise. *Science,* **316**, 1456. doi: 10.1126/science.1138679.

Dean, W. E., Zheng, Y., **Ortiz, J.D.,** and van Geen, A., 2006, Sediment Cd and Mo accumulation in the oxygen-minimum zone off western Baja California linked to global climate over the past 52 kyr. *Paleoceanography*, **21**, PA4209, doi:10.1029/2005PA001239.

Ortiz, J.D., O'Connell, S., DelViscio, J., Dean, W., Carriquiry, J., Marchitto, T., Zheng Y., and van Geen, A., 2004, Enhanced marine productivity off western North America during warm climate intervals of the past 52 kyr. *Geology*, **32**, 521-524.