LOOK ACADEMIC PUBLISHERS
OPEN ACCESS

INTERNATIONAL JOURNAL OF ENVIRONMENTAL & SCIENCE EDUCATION
e-ISSN: 1306-3065
2018, Vol. 13, No. 9, 689-701

Active Learning in an Introductory Oceanography Course: A Case Study of Promoting Scientific Interest and Literacy through Renewable Energy and Plate Tectonic Assignments

Jane Ellen Dmochowski [1*], Elizabeth K. Coward [2]

[1] *University of Pennsylvania, USA*
[2] *University of Delaware, USA*

* CORRESPONDENCE: janeed@sas.upenn.edu

ABSTRACT

Introductory Oceanography in the Earth and Environmental Science Department at the University of Pennsylvania has moved from a traditional lecture-based course to a Structured Active In-class Learning (SAIL) model, where students individually acquire the basics of the material before class, and in-class activities are designed to help students reach the higher order learning objectives through collaborative exercises. In implementing tools such as online modules, data-driven, quantitative in-class activities, pre- and post-lecture exercises, reflective writing assignments, and peer review, we aim to increase the science literacy of the student population, enhance their critical thinking skills, and correct common scientific misconceptions. This course is the product of three years of refinement via an annual SAIL university seminar with other faculty, the National Association of Geoscience Teachers Introductory Course Workshop at the 2014 American Geophysical Union conference, and surveys conducted by the University of Pennsylvania's Center for Teaching and Learning (CTL). While implementing active learning techniques with college students is not without complications, in this case study we explore how a SAIL course that utilizes technology to flexibly and creatively account for class size and STEM experience can foster an inquisitive classroom dynamic and knowledge acquisition, particularly as it relates to science literacy and increased interest in earth and environmental science. Results from pre- and post-instruction surveys, course reviews and student performance indices illustrate this objective. In addition to a summary of our assessment, readers will see examples of student exercises focused on ocean renewable energy and seafloor spreading that help students to understand fundamental concepts of plate tectonics, ocean tides and waves. Readers will also gain insight into the design and implementation of innovative teaching tools in introductory earth and environmental science courses.

Keywords: active learning, curriculum innovation, renewable energy, introductory STEM education, scientific literacy

INTRODUCTION

In addition to learning the fundamental concepts of Oceanography, we aim for our students to increase their science literacy so that they can vote intelligently, read the newspaper thoughtfully, make smart investments, appreciate nature and care for our planet. Improving science literacy in the United States has been delineated as a principal goal of primary through post-secondary education by multiple researchers and

Article History: Received 31 August 2018 ◆ Revised 22 September 2018 ◆ Accepted 22 September 2018

Table 1. Frameworks for principles of scientific literacy within the ocean, atmospheric, climate, energy and earth sciences

Literacy Initiative	Reference
Ocean Literacy: The Essential Principles of Ocean Sciences, K–12	Ocean Literacy Network, 2005
Atmospheric Science Literacy: Essential Principles and Fundamental Concepts of Atmospheric Science	Atmospheric Science Literacy Framework, 2007
Climate Literacy: The Essential Principles of Climate Sciences	U.S. Climate Change Science Program, 2009
Earth Science Literacy Principles	Wysession et al., M.E., 2012
Energy Literacy: Essential principles and fundamental concepts for energy education	U.S. Department of Energy, 2017

national scientific organizations (Jin & Bierma, 2013; Loucks-Horsley & Olson, 2000; Miller, 1983; National Research Council, 2007, 2008; Rutherford & Ahlgren, 1991). Multiple collaborations have constructed detailed frameworks for principles of scientific literacy within the ocean, atmospheric, climate, energy and earth sciences (**Table 1**).

However, most post-secondary introductory science classes for non-science majors remain large enrollment lectures, which often lack the opportunity in class to engage in rigorous scientific reasoning and thorough exploration of the material that can help students to understand scientific concepts and processes necessary for literacy. In an effort to increase learning and retention in large-enrollment courses, often with a focus on science literacy, many efforts have implemented online course assignments (Riffell & Sibley, 2005), various aspects of interactive engagement (Hake, 1998, 2007; Tlhoaele et al., 2014), in-class clicker questions and small group active learning activities (Deslauriers et al., 2011; Ebert-May et al., 1997; Tlhoaele et al., 2014), and data analysis in workshop format (Kitchen et al., 2003). These techniques and others, collectively categorized as “active learning”, have been chosen for their effective movement of students from passive observers into active investigator roles, and thus more accurately simulate a scientific climate.

Often such changes in course structure aim to engage students directly in scientific debate, research design and modeling within the classroom itself. The goal is to have students construct knowledge frameworks with the support of their professors, teaching assistants and peers. This is often achieved through a form of inquiry-based learning. According to the National Research Council, students that practice inquiry-based learning environments should a) be engaged in scientifically-oriented questions, b) give priority to evidence, encouraging them to develop and evaluate explanations that address scientific questions, c) formulate explanations from evidence to address scientific questions, d) evaluate their explanations in light of alternative explanations, e) communicate and justify their proposed explanations (Loucks-Horsley & Olson, 2000). We have made these five elements the focus of our pedagogical approach to the Introductory Oceanography course at the University of Pennsylvania.

In this paper we present student perceptions and learning outcomes stemming from the implementation of online video modules, with pre-and post-module quizzes, and in-class group exercises. This work emphasizes the results of previous studies that show applicable scientific reasoning beyond factual knowledge can help to achieve higher-order learning objectives and data fluency, while promoting student interest and accountability through cooperative engagement (Hoskinson et al., 2013; Johnson, 1991; Leech et al., 2004; McKeachie et al., 2002; Sandi-Urena et al,, 2011).

TEACHING AND ASSESSMENT METHODS

Survey

The Center for Teaching and Learning (CTL) -designed pre- and post-instruction surveys (see Supplemental Files), comprised of 5-component Likert scales, short answers, and true/false content questions, were used to assess student performance, ability to solve scientific problems, interest in applying scientific concepts, and scientific literacy (derived from Test of Scientific Literacy Skills (TOSLS) guidelines) (**Table 2**). The survey was administered online, by CTL, in the first 3 weeks of the semester, and again in the last 3 weeks, with participation incentivized with a very minimal participation point in the course. Eighty-four of the registered 88 students completed the pre-instruction survey, and 86 completed the post-instruction survey.

Table 2. Components and Results of the Center for Teaching and Learning (CTL) survey

Component	Skills assessed	Assessment form	Results
Performance	Retention and understanding of course material.	T/F and multiple choice questions.	Students scored on average 61% higher on content questions post-instruction.
Application	Reported capacity to apply and relate earth and environmental science concepts outside the classroom.	5 questions, ranked from 1 to 5 in agreement.	Significant ($p < 0.01$) increase in confidence in 3 out of 5 questions.[1]
Ability	Reported ability to solve scientific and, more specifically, Earth and environmental science problems.	5 questions, ranked 1 to 5 in confidence.	Significant ($p < 0.04$) increase in confidence in 3 out of 5 questions.
Science Literacy	Understanding scientific methods and the ability to organize, analyze, and interpret scientific information.	8 questions, 2 short answer and 6 ranked 1 to 6 in importance.	Significant ($p < 0.01$) increase in scientific literacy skills post-instruction.[2]

Course Structure

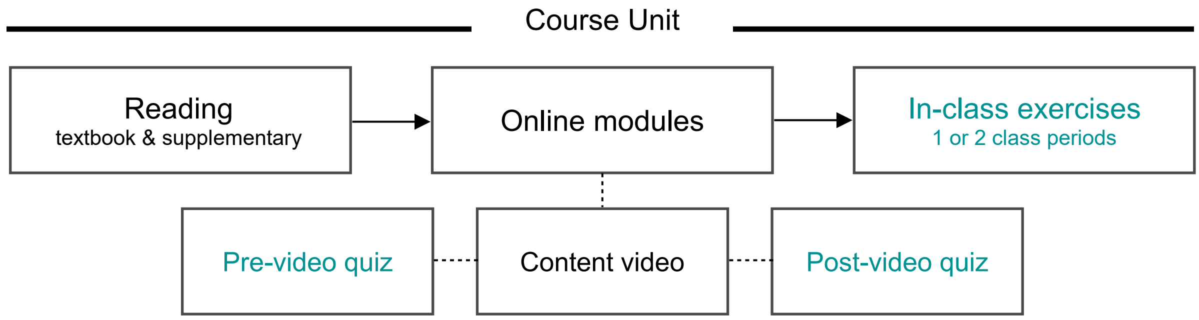
A diverse array of teaching tools is used in this course, encouraging learning flexibility and critical thinking through multimedia instruction and assessment, including 26 online modules, 27 in-class exercises, 2-7 minute mini-lectures given throughout the structured exercises in class, an online discussion board, and office hours (**Figure 1** and Supplemental Files). Online material is made available through the course management tool Canvas, www.instructure.com. Students are assessed based on two exams (comprising both multiple choice and long answer forms), post-module exercises, in-class exercises, and a 3-page paper or video project. The online modules consist of an initial question (e.g., "Why do we experience seasons on Earth?"), a textbook (Thurman et al, 1999) reading assignment, at least one video lecture produced by Dmochowski (on average 10-30 minutes in length), and several external links and/or videos, often including a news article relating to the subject of the module. The module concludes with a multiple-choice exercise, due before class, composed of 3 to 10 questions that help students to test their understanding of the material. Modules must be completed prior to class, and make up 13% of students' grades. There is some variation across modules, but most are designed to be completed in 1 to 2 hours, and 2 to 3 modules are due each week. Modules are constructed such that all information must be viewed sequentially in order to complete the assignment.

Course Expectations

Communication of course goals and intentions is vital to the success of this course design. Through a welcome letter, a thorough syllabus, published course objectives, a robust course management site, aforementioned text reminders throughout numerous modules, discussion boards, and repeated verbal reminders in class, we aim to continually communicate the evolution of and the goals for this course to the students. The letter also outlines the basics of the course structure and expectations, reiterates the instructor's enthusiasm for teaching an active learning course and why we believe it helps students to succeed. This letter is then incorporated into the first module, alongside basic technological information for the course management system, links to the syllabus and instructions on completing later modules. The importance of attendance, particularly to an active learning classroom, is also emphasized to students, highlighting that failure to complete online modules is equivalent to missing class. Students are told that regularly attending class and participating is critical to their learning and success in the course, and that it is required. These expectations clarify the often unfamiliar structure of an active learning course, and highlight a clear path to student success.

In-class Exercises

In class, students work in groups of three at circular tables hosting two to three groups, allowing for inter-group exchange, while the instructor and at least 2 teaching assistants circulate in the room, answering questions and encouraging groups to work effectively together. Groups are announced online before class, and new groups are formed each class period. Roughly 1/3 of the time students were able to choose their own groups.



Unit assessments	Learning goals	Assessment form	Example
Pre-video quiz	Broad understanding of foundational concepts and common misconceptions.	1 to 5 ungraded short-answer questions. Open-ended, meta-cognitive exercise to emphasize pre-module knowledge.	Why do we experience seasons on Earth?
Post-video quiz	Comprehension and retention of assigned reading and video content.	3 to 5 first-order multiple choice or fill-in-the-blank questions, prioritizing understanding of key terminology and concepts.	During the vernal equinox, where is the Earth's solar radiation most intense? **A. the equator.** B. 23 degrees south.C. 23.5 degrees north.D.the norh pole.
In-class assignments	Ability to apply unit concepts to data-driven, quantitative scenarios.	Data tables, plots and short answer synthesis questions using public, peer-reviewed data.	See appendix.

Figure 1. Course unit progression and assessments

During in-class exercises students apply the knowledge they gained in the modules to analyze published data, integrate their calculations, and compare these results both against other groups' observations and peer-reviewed research in order to formulate an evaluation. Assignment structures utilize a variety of scaffolding aimed at translating science education research in teaching problem solving (Kober, 2015) into practice. Class begins with announcements and a short (usually 3-5 minute) introduction to the assignment, and then students work through each section of the exercise sequentially. Students are encouraged to develop and evaluate answers and explanations as a group, formulate explanations from evidence to address scientific questions, and use peer-review to communicate and evaluate their explanations. Sections are interspersed with short "check-in" lectures, in which difficult concepts are reviewed, student explanations are given and reviewed, data is reframed, or concept clicker questions are asked. Colored flags are on the tables to help groups indicate if they need help (red) or are finished and ready to move on (green). Each in-class assignment is comprised of 4 to 5 sections, and each section is designed to occupy roughly 20 minutes of the class period. One assignment for each group is due at the end of class, and exercises are graded and returned to the students by teaching assistants. The rubric for grading consists of the following categories: Thoroughness/Completeness (3 points), Group Dynamics (3 points), and Correctness (4 points), emphasizing the learning process and group dynamics over accuracy, which differentiates this assessment from the online module quizzes and exams.

Final Projects

Near the end of the course students must submit either A) a 7 to 10-minute video that clearly and creatively provides an in-depth exploration (background, interesting examples, and both quantitative and qualitative analysis) of a concept introduced in class (and the highest-scoring ones, with permission, are put in the

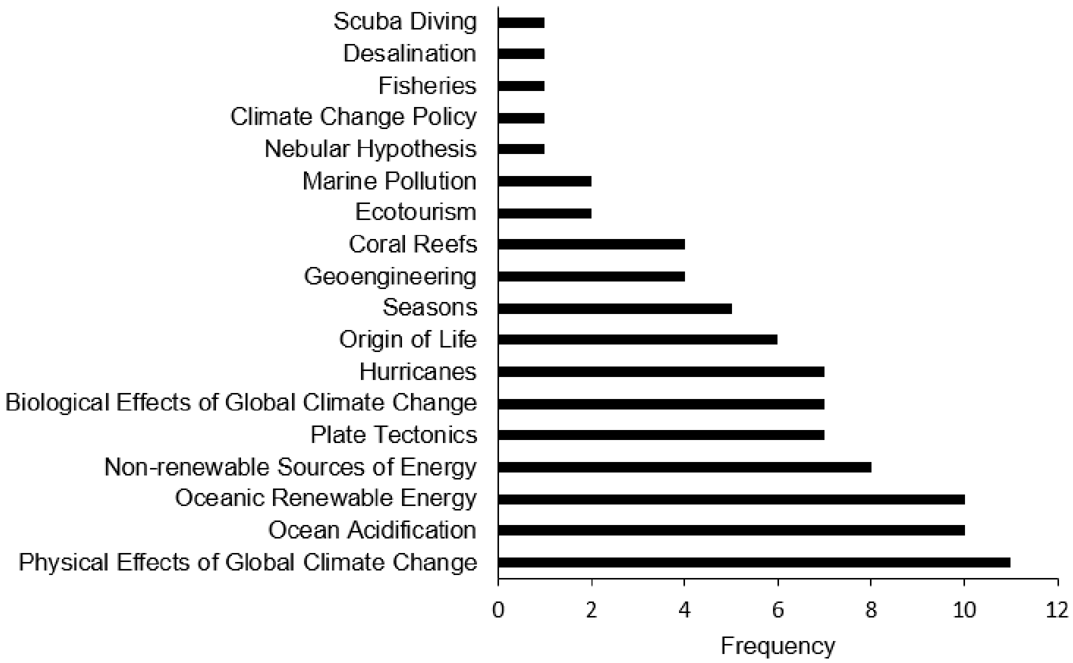


Figure 2. Frequency of topics chosen for final projects

appropriate modules for future semesters), or B) a **3**-page opinion paper on any topic in the course, using peer-reviewed, scientific evidence to make an argument. Students are instructed to describe and summarize any subject related to oceanography and then use evidence to make an argument, forcing them to learn more about at least one aspect of oceanography, consider various viewpoints, arguments, evidence, data and conclusions from various sources. Topics chosen are summarized in **Figure 2**.

EXAMPLE COURSE UNITS

The development of student knowledge and higher-order learning in this course is most evident when following one course unit concept through all three stages of assessment: pre-instruction online learning, in-class assignments, and exams (**Figure 1**). In this progression, our goals align with those of the National Research Council's, as we aim to engage students directly with the scientific process by encouraging them to develop and evaluate explanations that address scientific questions, formulate explanations from evidence, evaluate their own explanations through peer review, and communicate and justify their proposed explanations.

Tides and Waves

In our exploration of tides and waves (also see Supplemental Files for full assignments), students learn how waves and tides are generated, predicted, vary around the globe, and interact with the coastline. The in-class exercises associated with this module also aim to instill an appreciation of the connection of physical oceanography concepts to renewable energy from the ocean and enable students to connect concepts of tides and waves to their life experiences and interests. These in-class exercises are completed during two 80-minute class periods, one in which students use National Oceanic and Atmospheric Administration (NOAA) data to calculate potential wave power, and one in which they use NOAA data to calculate potential tidal power.

The Tidal in-class exercise is structured as follows:

A. Fill-in-the-blank questions regarding the basics of tides.

B. Students identify three stations that are of personal interest and indicate the tidal pattern range and predicted tide for a particular time and day using data from the NOAA website (http://tidesandcurrents.noaa.gov/tide_predictions.html). They plot these locations on a figure of global amphidromic points and cotidal contours and determine if the tidal range corroborates with information in the figure.

C. Students calculate tidal energy and power generated at three stations in Northern California, Galveston, Texas, and the Bay of Fundy using data from http://tidesandcurrents.noaa.gov/tide_predictions.html .

   a. They determine tidal pattern, number of high tides per day and the total tidal range for these stations.

   b. They calculate the potential energy that can be generated through tidal barrage systems—dam-like systems that harness energy from collected water moving in and out of a coastal area due to tidal forces--using the following equation, with a standard barrage basin area (A).

$$E = 0.5A\rho g h^2$$

   where, h is the vertical tidal range in meters, A is the horizontal area of the barrage basin in meters squared, ρ is the density of seawater, and g is acceleration due to gravity.

   c. Students use their calculations to determine which site is best suited for a tidal power plant and brainstorm other potential locations using their understanding of global tidal ranges and patterns.

The Waves in-class exercise is structured as follows:

A. Students are prompted with question reminding them that waves are generated by wind passing over the surface of the sea, transferring energy to the waves, and then are asked, "If one gets electricity from waves what, ultimately, is the source of this energy?", directing them towards the overarching understanding that wave power is ultimately solar power. They are shown a figure of global average significant wave height for January and July, and are asked if it appears that wave power plants would be a reliable source of energy year round at any locations. This exercise highlights that waves are a fairly unreliable source of power, but that there are patterns indicating where one may get more power from waves throughout the year.

B. Students calculate wave energy and power generated at three stations, building largely on the conceptual framework of the Tide in-class exercise, as students calculate the wave potential energy at each of the same three sites using the following equation and data obtained from the NOAA National Data Buoy Center website, http://www.ndbc.noaa.gov:

$$P = H^2 T \left(\frac{\rho g^2}{64\pi}\right)$$

where, P is power, ρ is the density of seawater, g is acceleration due to gravity, H is significant wave height, and T is wave period in seconds.

C. Students are reminded that before we compare our data to what was calculated for a tidal power plant, they need to consider that they calculated the power generated per one meter, and these data must be normalized to a constant area for an accurate comparison. After they have completed their calculations, they must decide at each site, whether they would advocate for a wave power plant, a tidal power plant, or neither - and why. To contextualize these results, students compare both their hypothetical tidal and wave power plants to average outputs of active coal power plants, finding that the latter dwarfs even the most productive site.

D. Lastly, students are asked if there are considerations we have not accounted for in our analysis, and discuss as a class how these could influence our final evaluations (e.g., wave power is not consistent annually; our use of a deep water wave power equation; the conundrum that large waves may lead to more power generations, but are more destructive to instrumentation; ease and cost of building the structure, societal qualms about power plants built on beachfront property). We provide time for them to discuss and revise their answers before handing in the completed assignment.

Student performance on the post-online module exercises (Tides: 89%; Waves: 95%; Post-module exercise average for all modules: 92%) indicates most students have a mastery of the basic concepts after the online modules, but these exercises do not elevate students to higher-order learning objectives. However, students do relatively well on these two in-class exercises (Tides, 92%, Waves, 91%; average in-class score for all in-class exercises, 93%). Student discussion in class and on the online discussion boards, as well as their choice of topics for their final projects gave us reason to believe these in-class assignments stimulated student interest. Despite these topics making up just 1% of the course textbook material, for the final project (3-page paper or video), for which students choose any oceanography topic, 10/88 students chose a project that in some way was derived from the information they learned in these 2 exercises (**Figure 2**). In fact, the vast majority of their projects stemmed from course material that was introduced through in-class assignments, including all of the 10 most popular topics shown in **Figure 2**.

Seafloor Spreading

As part of the course on Plate Tectonics, we examine seafloor spreading, the active formation of new crust at oceanic ridges due to mantle convection, and students are asked to synthesize previous modules on paleomagnetism and plate tectonics into a sophisticated, working understanding of global physical oceanographic processes. We aim to clarify the misconception of the magnetic field causing plate tectonics (Marques & Thompson, 1997; McKenney & Webster, 2004), and instill a deep understanding of how paleomagnetism helps record past plate motions in the geologic record. Post-module questions queried principally definitions of class concepts and definitions, such as those of spreading centers and Curie points, while in class, students were confronted with primary geospatial data and asked to identify, annotate, and analyze the provided information utilizing the textual toolkit they obtained at home. More specifically, the Seafloor Spreading in-class exercise is structured as follows:

A. Students identify key features of the Mid-Atlantic Ridge (MAR), generate a quantitative analysis of spreading rates based on several paleomagnetic isochrons shown, and explain why - or why not - all of the possible half-rates computed agree with each other.

B. Students are asked to brainstorm other methods scientists could use to determine both current and past spreading rates.

C. Students are asked “What does Earth’s magnetic field and the field’s periodic reversals have to do with plate tectonics?”, a synthesis question that urges students to think critically about the underlying mechanisms driving these two processes, and correct common misconceptions of tectonic activity.

D. Students are presented with a paleomagnetic time scale, and asked to determine the spreading rate of the East Pacific Rise, demonstrating that two types of data and analysis can provide comparable results. Students are asked to characterize both spreading centers (MAR and EPR) based on their calculated rates

The assignment concludes with a critical discussion of current research in the field, reflecting on advances that have enabled our understanding of seafloor spreading, how such data is collected, and what the limitations are of the analytic process itself.

RESULTS

Survey

The surveys were designed to assess student performance, ability to solve scientific problems, interest in applying scientific concepts, and scientific literacy (derived from TOSLS guidelines) (**Table 2**). Ability was examined through five self-assessment Likert scale questions, in which students ranked their “ability to solve problems in their science courses” and “ability to solve earth science problems in particular” from 1 to 5, pre- and post-instruction (**Figure 3**). Survey Results from student responses to Likert scales, often the subject of statistical debate, were analyzed for changes in student confidence or agreement post-instruction. Quantitative results are presented as divergent stacked charts to assess course-wide trends, and statistical significance is reported as the result of paired t-tests, as suggested by de Winter and Dodou (2010) and Norman (2010). While we recognize the hazards of application of parametric tests when the assumptions of the t-test may not be valid, particularly those of normality, we here follow the findings of de Winter and Dodou (2010) and Norman (2010) in suggesting that the large sample size ($n = 85$) of survey respondents allows for appropriate use of these tests.

Across all students, improvement was observed in three of the five categories, while the remaining two categories displayed no substantial changes. Students reported significant improvements in ability scores (general science ability: mean of 3.43, out of 5, pre-instruction, 3.63 post-instruction, $p=0.01$; earth science ability: mean of 3.06 pre-instruction, 3.53 post-instruction, $p<0.001$). Comparisons between students of STEM, non-STEM and undeclared majors revealed that non-STEM students reported the largest increases in ability (non-STEM, general science: mean of 3.23 pre-instruction, 3.48 post-instruction, $p=0.07$; non-STEM, earth science: mean of 2.81 pre-instruction, 3.45 post-instruction, $p<0.001$; STEM, general science: mean of 4 pre-instruction, 3.87 post-instruction, $p=0.48$; STEM, earth science: mean of 3.43 pre-instruction, 3.73 post-instruction, $p=0.16$).

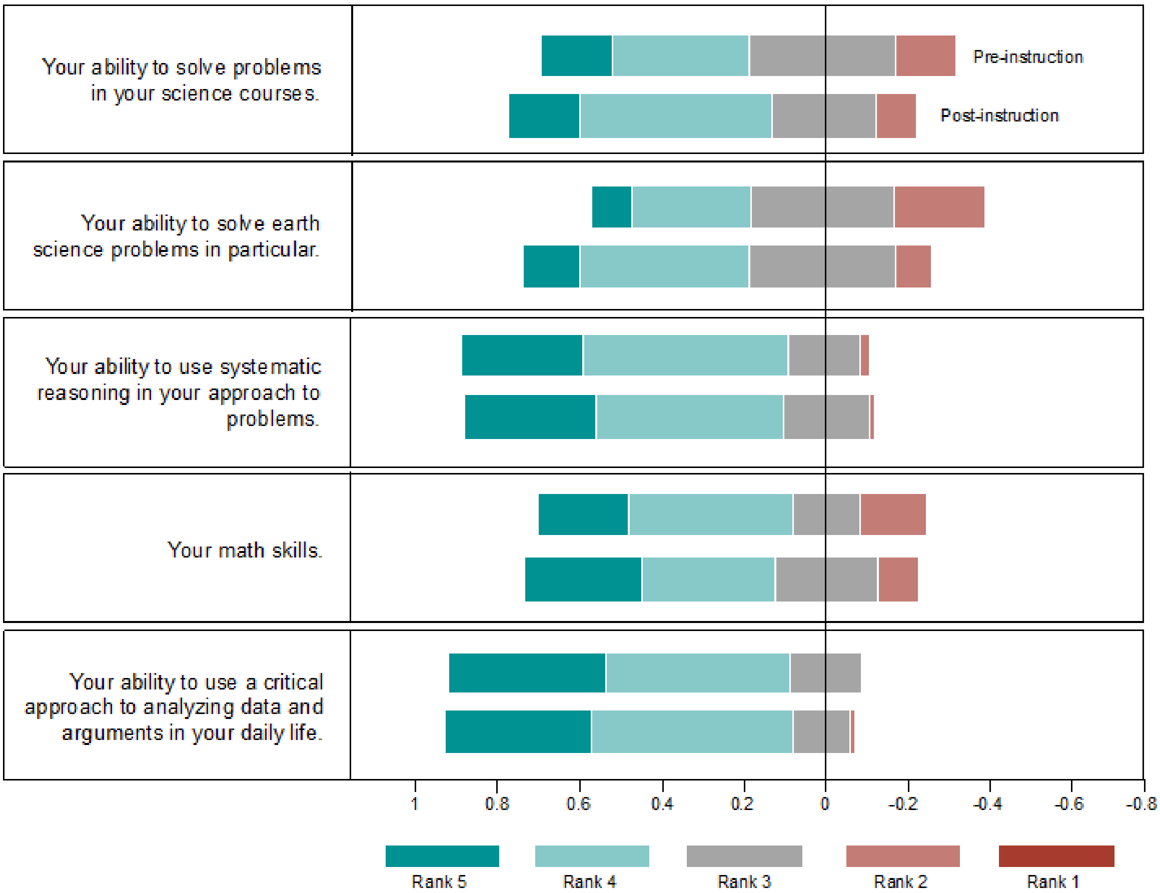


Figure 3. Center for Teaching and Learning (CTL) survey results, pre- and post-instruction, from five questions assessing student's ability to address scientific questions

Table 3. Normalized score gain of STEM, Non-STEM and undeclared majors on content questions, as determined from pre- and post-instruction scores in the Center for Teaching and Learning (CTL) survey

Normalized Score Gain	Mean	St. Dev
STEM Majors	0.75	0.38
Non-STEM Majors	0.58	0.36
Undeclared Majors	0.50	0.42
All Students	0.61	0.40

These results were supported by indices of course performance included in the surveys, namely the results from the "concept questions" (**Table 3**), in which students answered five questions sourced directly from in-class assignments stratified across course material. Student responses post-instruction scored at 83.71%, a 17.81±3.11 percentage point increase after course completion.

Students also report an increased level of interest in Earth Science, agreeing more strongly after the class than before with the statements, "I feel I have a basic understanding of how earth science relates to real world problems." ($p<0.001$), "I often connect what I know about earth science with events in my daily life." ($p<0.001$) (**Figure 4**). Survey results display marked differences amongst student major populations. These results are particularly robust for non-STEM and undeclared students, who experienced 7.20% ($p<0.01$) and 7.80% ($p<0.05$) increases, respectively, in response to "I feel I have a basic understanding of how earth science relates to real world problems.", 7.60% ($p<0.01$) and 12.2% ($p<0.05$) in response to "I often connect what I know about earth science with events in my daily life."

Students scored significantly higher ($p = 0.001$) on science literacy questions (**Table 4**), many of which were derived from the Test of Scientific Literacy Skills (TOSLS) (Gormally et al., 2012), improving from 65.9 ±19.46% before instruction to a mean score of 83.71 ± 21.10% correct answers after instruction.

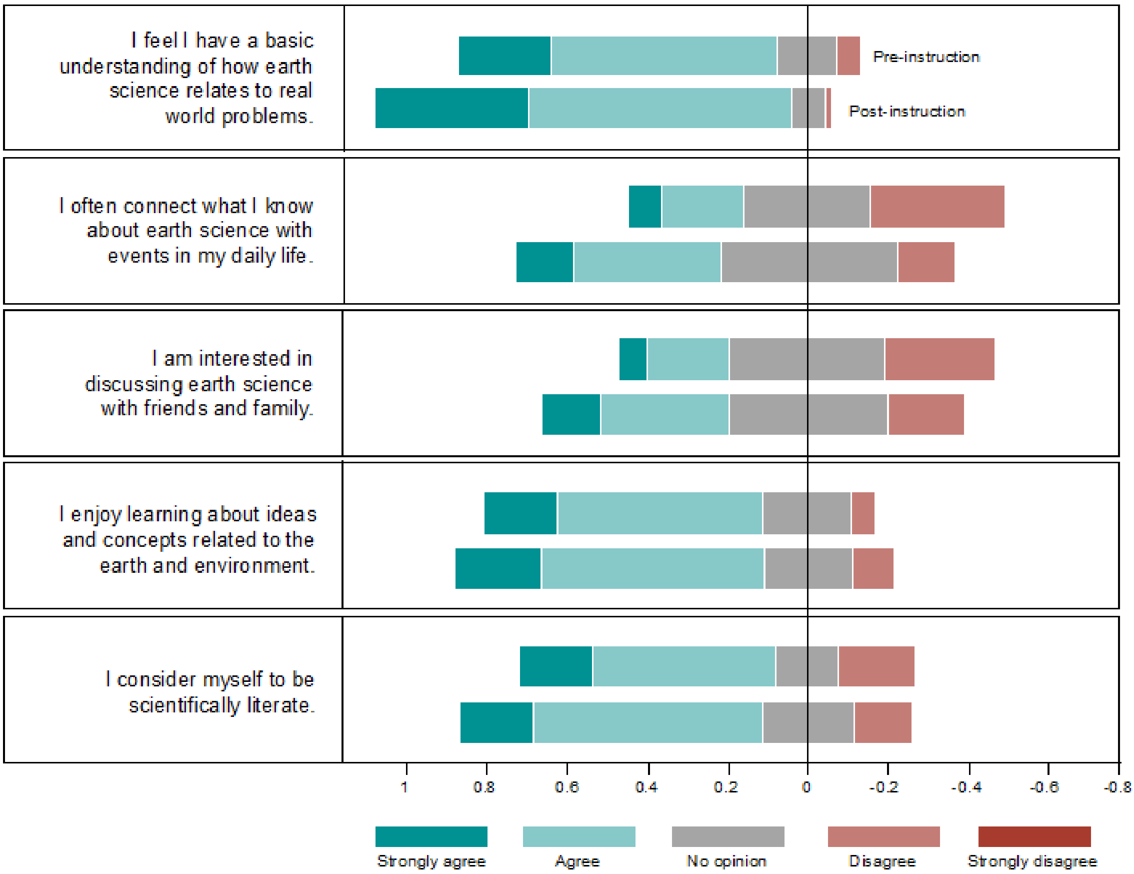


Figure 4. Center for Teaching and Learning (CTL) survey results, pre- and post-instruction, from five questions assessing student's application and engagement with earth science material

Table 4. Results from a selection of questions from the TOSLS test designed to measures scientific literacy skills

Science Literacy Index	Mean	St. Dev	*p* Value
Pre-Instruction	65.9	19.46	~
Post-Instruction	83.71	21.1	**0.001**

When assessing how effective students thought various course activities were (ranked 1-5; 1, "Not at all effective"; 5, "Very effective"), only 39% of students ranked "Watching video lectures and taking notes" either 4 or 5. Only 60.4% of respondents reported "sometimes" or "always" to the question "After completing the online modules, did you feel prepared to work on the in-class problems?"

This course fulfills a general requirement for undergraduate students at the University of Pennsylvania. As such, we assume our student profile matches that of an average student at the University of Pennsylvania, having an average SAT composite score of 2163 (Incoming University of Pennsylvania's Class Profile, 2015). The student survey population (81 respondents out of 88 enrolled in the course completed both surveys; 84 completed the pre-class survey, and 86 completed the post-class survey) self-identified as 52% male (43 students) and 46% (38) female (1 other did not state). Ten percent of the respondents identified as first-generation college students. Racial and Ethnicity were reported as follows: 29 White and Caucasian; 29 Not stated; 10 Asian, South Asian, and Asian American; 6 Mixed race; 4 Black and African American; 4 Hispanic.

Class Data

The combination of data-driven, quantitative study and discussion-based problem solving in a collaborative setting in the in-class assignments appear to promote accessibility, particularly for non-STEM majors. Both through informal observation in class and the high average on the in-class assignments (95%) we observed an increased ability to answer difficult, conceptual questions when working together in a group.

Student participation on the online discussion boards was encouraged by awarding a maximum of 5 points (roughly 0.7% total class points possible) for posting at least two questions or one answer throughout the semester. Of 88 students in the course, 74 posted at least once throughout the semester, but only 39 students posted twice or more.

Assessing interest in current applications of oceanographic concepts is not straightforward in a case study of this nature; however, the student choice of final paper topics (**Figure 1**), showed ‘Physical Effects of Global Climate Change’, ‘Ocean Acidification’, and ‘Oceanic Renewable Energy’ served as the top three subjects, all topics that were addressed in in-class exercises, despite given considerable freedom in choosing any topic related to the oceans.

In the 2015 class of 88 students, the average attendance, excluding near perfect attendance on exam days, was 88%. Attendance was not taken in the class prior to its transformation into a SAIL class. However, this appears high compared to anecdotal evidence and published reports of college lecture attendance. In a 1993 study of absenteeism in undergraduate economics classes, “School A”, with a profile similar to our university—a private university with 6,000 undergraduates and a Barron’s Profile of American Colleges ranking of “highly competitive”— was found to have an average attendance of 60% (Romer, 1993). More recently, attendance rates of 81.5% were reported in a microeconomics course with 6o students (Marburger, 2001) and 70% in two separate biology classes (Moore et al., 2003). There was not a significant difference in the average scores, graded out of 10 points, on in-class exercises for groups chosen randomly (M=9.515, SD=0.256) and groups that were chosen by the students (M=9.608, SD=0.199); t=-1.0011, p=0.3285.

DISCUSSION AND CONCLUSIONS

Survey and Class Data Results

The significant improvement in attitude toward Earth Science for non-STEM and undeclared students indicate that course goals in stimulating interest and understanding of earth and environmental science as a fundamental building block are being met. Additionally, the applied and current nature of the topics students chose for their final papers suggests students were most engaged and confident applying scientific inquiry to areas of ongoing research and debate, especially when exposed to some aspect of the inquiry in an in-class activity.

It is clear from our analysis of student involvement on the Discussion Board and their self-reported effectiveness of the effectiveness of the online components that there is considerably room for improvement of the videos and supplemental information; however, students are clearly doing well on the in-class exercises, which rely on learning foundational material outside of class, so perhaps the online modules are effective, but not well-liked by the students.

Lessons Learned and Recommendations

Several practical lessons were learned in the process of re-designing and teaching this introductory earth and environmental science course to incorporate more active and inquiry-based learning. Additionally, while we have both very much enjoyed teaching this SAIL course, and our pre- and post-class surveys and class assessments suggest the revision of this class into an active-learning course is reaching its goals of promoting scientific interest and literacy, our case study also highlights room for improvement. For example, continued effort must be put toward making the pre-class modules effective and incentivizing students to use them and the online discussion boards more fully, for pre-class preparation. The in-class exercises must continue to be honed to challenge all students and allow for group work to be done effectively and in a timely manner, while best achieving higher-order learning objectives.

While the students’ final projects and in-class exercises are effective strategic assessments, being well aligned with our higher order learning course objectives, shown to be an important element of encouraging complex cognitive thinking (Bergendahl, 2005), in our exams, we found few examples where we assess students at the highest levels of understanding that they are able to achieve in the in-class exercises. This may be a place where further course development is necessary to keep up with the evolution of the course. In the future, we will potentially use two-stage exams, a method that many researchers and instructors (Heller & Hollabaugh, 1992; Heller et al., 1997; Wieman, Rieger, & Heiner, 2014) have found fosters the type of collaborative learning we have cultivated using our in-class exercises (Heller & Hollabaugh, 1992; Heller et al., 1997; Wieman et al., 2014).

We found it helpful to consider carefully which lower-order objectives could be addressed outside of class time, and how the students can be directed and incentivized to learn this material before class. Our solution was to provide online modules, to be completed before class, with videos and support material and quizzes at the end that counted, albeit not heavily, toward the student's final grade. Keeping videos relatively short (approximately 20 minutes), seemed, anecdotally, to work best for students. Based on informal student feedback, using exceptionally well done videos made by former students (as part of their 3 page paper or video assignment) in the modules also appealed to many students and gave them motivation to make excellent videos for their final projects.

It can be a challenge to gauge the difficulty of in-class exercises and to budget in-class time appropriately. Flexibility—having extra slides or other materials that allow one to add or decrease class discussion or group work on the fly—is helpful the first time through an assignment. We found it to be important to pay attention to the social dynamics of the room and design some flexibility into the course structure and policies to respond to any issues. In our experience, the transition to a more active classroom is made easier by allowing students to be "in on it", as we discussed above in the *Course Expectations* section. Knowing which objectives each assignment is fulfilling, and communicating this to students, can be very helpful (see Supplemental File of Course Objectives). One of the most rewarding aspects of this style of teaching, we believe, is that it allows instructors to use a portfolio of teaching styles and technology to address an array of learning styles.

Future Work

More studies are necessary to understand if and how this method of instruction can be more effective than a traditional classroom. For example, while exam performance has increased since this course has been taught in the SAIL style, in line with findings of other researchers who show active learning increases (Freeman et al., 2014) or at the least does not decrease (McConnell et al., 2003) exam performance, many confounding variables (classroom size, class meeting frequency, student preparation, number of teaching assistants, group size, gender distributions, etc.) have not been held constant; therefore, we have not been able to directly compare learning outcomes to a similar group taught the same material via a traditional lecture style. Additionally, how the instructor can best form groups and encourage constructive group work continue to be important fields of investigation. As explored in depth by (Johnson et al., 2006) and others, focusing on cooperation over competition and keeping a close eye on group dynamics is very important for effective group work. We use incentives for effective group work (see In-Class Exercises above), a well-designed classroom, frequent interactions between the groups and the instructor and teaching assistants to encourage this collaboration. However, interestingly we found no difference in the quality of work when students chose their own versus when they were assigned groups.

In addition to the dynamics of the group work, deciding how and when to address student misconceptions is incredibly important. Multiple studies (Bransford et al., 1999, National Research Council, 1999; and others) have illustrated the importance of understanding the need to address student preconceptions; stating clear learning outcomes, using these to both design effective pedagogy and assess student work, providing frequent, organized feedback to students, giving students multiple opportunities to form their own framework for understanding the course material, designing exercises to help students build on this foundation, and encouraging a metacognitive approach to the student's learning experience. Our work reinforces these recommendations.

ACKNOWLEDGEMENTS

We would like to thank the staff of the Center for Teaching and Learning at the University of Pennsylvania, who organized and facilitated the many faculty and teaching assistant seminars that helped enlighten this work, as well as the many faculty participants of those seminars. We especially acknowledge the work of Julie McGurk, Bruce Lenthall, and a very special thanks to Emily Elliot who also helped to design, conduct and interpret our surveys. We are also very grateful to the many faculty and teaching assistant participants in these seminars, as well as the other teaching assistants in the course.

Disclosure statement

No potential conflict of interest was reported by the authors.

Notes on contributors

Jane Ellen Dmochowski – Department of Earth and Environmental Science, University of Pennsylvania, United States of America.

Elizabeth K. Coward – Interdisciplinary Science and Engineering Laboratory, University of Delaware, United States of America.

REFERENCES

Atmospheric Science Literacy Framework. (2007). Atmospheric science literacy—Essential principles and fundamental concepts of atmospheric science. Retrieved on 10 December 2015 from http://eo.ucar.edu/asl/pdfs/ASLbrochureFINAL.pdf

Bergendahl, C., & Tibell, L. (2005). Boosting complex learning by strategic assessment and course design. J. Chem.Educ, 82, 645. https://doi.org/10.1021/ed082p645

Bransford. J. D., Brown, A., & Cocking, R. (1999). How people learn: Mind, brain, experience, and school. Washington, DC: National Research Council.

Climate Literacy. (2009). U.S. Climate Change Science Program: Oceanic and Atmospheric Administration (NOAA) and the American Association for the Advancement of Science (AAAS). Retrieved from http://oceanservice.noaa.gov/education/literacy/climate_literacy.pdf

De Winter, J. C., & Dodou, D. 2010. Five-point Likert items: t test versus Mann-Whitney-Wilcoxon. Practical Assessment, Research & Evaluation, 15, 1-12.

Deslauriers, L., Schelew, E., et al. (2011). Improved learning in a large-enrollment physics class. Science, 332, 862-864. https://doi.org/10.1126/science.1201783

Ebert-May, D., Brewer, C., et al. (1997). Innovation in large lectures: Teaching for active learning. Bioscience, 47, 601-607. https://doi.org/10.2307/1313166

Freeman, S., Eddy, S. L., et al. (2014). Active learning increases student performance in science, engineering, and mathematics. Proceedings of the National Academy of Sciences, 111, 8410-8415. https://doi.org/10.1073/pnas.1319030111

Gormally, C., Brickman, P., & Lutz, M. (2012). Developing a Test of Scientific Literacy Skills (TOSLS): measuring undergraduates' evaluation of scientific information and arguments. CBE-Life Sciences Education, 11, 364-377. https://doi.org/10.1187/cbe.12-03-0026

Hake, R. R. (1998). Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. American journal of Physics, 66, 64-74. https://doi.org/10.1119/1.18809

Hake, R. R. (2007). Six lessons from the physics education reform effort. Latin american journal of physics education, 1, 24-31.

Heller, P., & Hollabaugh, M. (1992). Teaching problem solving through cooperative grouping. Part 2: Designing problems and structuring groups. American Journal of Physics, 60, 637-644. https://doi.org/10.1119/1.17117

Heller, P., Keith, R., & Anderson, S. (1992). Teaching problem solving through cooperative grouping. Part 1: Group versus individual problem solving. American journal of physics, 60, 627-636. https://doi.org/10.1119/1.17118

Hoskinson, A., Caballero, M. D., et al. (2013). How can we improve problem solving in undergraduate biology? Applying lessons from 30 years of physics education research. CBE-Life Sciences Education, 12, 153-161. https://doi.org/10.1187/cbe.12-09-0149

Jin, G., & Bierma, T. (2013). STEM for non-STEM Majors: Enhancing Science Literacy in Large Classes. Journal of College Science Teaching, 42, 20-26. https://doi.org/10.2505/4/jcst13_042_06_20

Johnson, D. W. (1991). Cooperative Learning: Increasing College Faculty Instructional Productivity. ASHE-ERIC Higher Education Report No. 4, 1991. ERIC.

Johnson, D. W., Johnson, R. T., & Smith, K. A. (1998). Active learning: Cooperation in the college classroom. ERIC.

Kitchen, E., Bell, J. D., et al. (2003). Teaching cell biology in the large-enrollment classroom: methods to promote analytical thinking and assessment of their effectiveness. Cell Biology Education, 2, 180-194. https://doi.org/10.1187/cbe.02-11-0055

Kober, N. (2015). Reaching students: What research says about effective instruction in undergraduate science and engineering. ERIC.

Leech, M. L., Howell, D. G., et al. (2004). A guided inquiry approach to learning the geology of the US. Journal of Geoscience Education, 52, 368-373. https://doi.org/10.5408/1089-9995-52.4.368

Loucks-Horsley, S. and Olson, S., 2000. Inquiry and the national science education standards: A guide for teaching and learning.

Marburger, D. R. 2001. Absenteeism and undergraduate exam performance. The Journal of Economic Education, 32, 99-109. https://doi.org/10.2307/1183486

Marques, L. & Thompson, D. 1997. Misconceptions and conceptual changes concerning Continental Drift and Plate Tectonics among Portuguese students aged 16-17. Research in Science & Technological Education, 15, 195-222. https://doi.org/10.1080/0263514970150206

McConnell, D. A., Steer, D. N., et al. 2003. Assessment and active learning strategies for introductory geology courses. Journal of Geoscience Education, 51, 205-216. https://doi.org/10.5408/1089-9995-51.2.205

McKeachie, W. J., Lin, Y., et al. 2002. Creationist vs. evolutionary beliefs: Effects on learning biology. The American Biology Teacher, 64, 189-192. https://doi.org/10.2307/4451275

McKenney, R. & Webster, J. 2004. Magnetism, the Earth as a Magnet, and Seafloor Banding—How Much Magnetism is Enough? Journal of Geoscience Education, 52, 352-362. https://doi.org/10.5408/1089-9995-52.4.352

Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. Daedalus, 29-48.

Moore, R. (2003). Attendance and performance. Journal of College Science Teaching, 32, 367.

National Research Council. (1999). Transforming undergraduate education in science, mathematics, engineering, and technology. National Academies Press.

Norman, G. (2010). Likert scales, levels of measurement and the "laws" of statistics. Advances in health sciences education, 15, 625-632. https://doi.org/10.1007/s10459-010-9222-y

Ocean Literacy Network. (2013). Ocean Literacy: The essential principles of ocean sciences for learners of all ages. Silver Springs, MD: National Oceanic and Atmospheric Administration.

Riffell, S., & Sibley, D. (2005). Using web-based instruction to improve large undergraduate biology courses: An evaluation of a hybrid course format. Computers & Education, 44, 217-235. https://doi.org/10.1016/j.compedu.2004.01.005

Romer, D. (1993). Do students go to class? Should they? The Journal of Economic Perspectives, 7, 167-174. https://doi.org/10.1257/jep.7.3.167

Rutherford, F. J., & Ahlgren, A. (1991). Science for all Americans. Oxford university press.

Sandi-Urena, S., Cooper, M. M., et al. (2011). Students' experience in a general chemistry cooperative problem based laboratory. Chemistry Education Research and Practice, 12, 434-442. https://doi.org/10.1039/C1RP90047A

Thurman, H. V., Trujillo, A. P., et al. (1999). Essentials of oceanography. Prentice Hall Upper Saddle River, NJ.

Tlhoaele, M., Hofman, A., et al. (2014). Using clickers to facilitate interactive engagement activities in a lecture room for improved performance by students. Innovations in Education and Teaching International, 51, 497-509. https://doi.org/10.1080/14703297.2013.796725

U.S. Department of Energy, Energy Literacy: Essential Principles and Fundamental Concepts for Energy Education, energy.gov, Version 5.0: March 2017.

Wieman, C. E., Rieger, G. W., & Heiner, C. E. (2014). Physics exams that promote collaborative learning. The Physics Teacher, 52, 51-53. https://doi.org/10.1119/1.4849159

Wysession, M. E., LaDue, N., et al. (2012). Developing and applying a set of earth science literacy principles. Journal of Geoscience Education, 60, 95-99. https://doi.org/10.5408/11-248.1