What's in New York City's water?

Aquatic biodiversity in a mosaic of human impact

Write the author list here as a single paragraph. List authors by first name (optional middle initial or middle name) followed by last name. Separate multiple authors by commas. Use superscript numbers to link authors to specific affiliations, and symbols *,†,†† for author notes (such as corresponding author).

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Abstract

A growing body of literature supports using evidence-based teaching techniques (EBTs) to address STEM education failures, and outlines key strategies highlighting active teaching and a research framework. Although relatively low-cost public institutions play increasingly important roles in STEM education, there is insufficient knowledge of how well these strategies work in such settings. Representing the first steps in a long-term plan, we aim to immerse College of Staten Island undergraduates enrolled in General Biology, a gatekeeper course, in EBT-based classes focused on evolutionary and biodiversity research. In this lesson each experimental lab section of the General Biology sequence is incorporating research framed within a seminal scientific theory illuminating the unity and diversity of living systems. Students are exploring the Theory of Evolution by Natural Selection through ecological and genetic research on field-collected aquatic biodiversity samples. Our study is testing the following hypothesis: *In comparison to controls, significantly higher student learning gains and satisfaction will occur in courses taught using EBTs*. Outcomes are being evaluated through surveys and course observations. The data will be used to develop and widely disseminate a transformative and adaptable model to improve STEM education more broadly. The proposed study will inform the science learning community regarding active learning and research approaches in STEM education at an urban public university, with applications for other areas. The project will reach underrepresented groups, lead to a more effective and diverse workforce, address contemporary environmental conservation issues, and serve as the basis for grant applications.

Article Context:

Course

- Biochemistry
- Cell Biology
- Developmental Biology
- Genetics
- Microbiology
- Molecular Biology
- Introductory Biology
- Bioinformatics
- Evolution
- Ecology
- Anatomy-Physiology
- Neurobiology
- Plant Biology
- Science Process Skills

Course Level

- Introductory
- Upper Level
- Graduate
- High School
- Other

Class Type

- Lecture
- Lab
- Seminar
- Discussion Section
- On-line
- Other

Audience

- Life Sciences Major
- Non-Life Science Major
- Non-Traditional Student
- 2-year College
- 4-year College
- University
- Other

Class Size

- 1 – 50
- 51 – 100
- 101+

Assessment Type

- Assessment of individual student performance
- Assessment of student groups/teams
- Assignment
- Exam/quiz, in class
- Exam/quiz, take home
- Homework
- Answer clicker-type question(s)
- Answer essay question(s)
- Answer fill in the blank question(s)
- Answer multiple choice question(s)
- Answer short answer questions(s)
- Answer true/false question(s)
- Create a concept map
- Create a diagram, drawing, figure, etc.
- Create a website
- Create graph, table etc. to present data
- Design an experiment or research study
- Design/present a poster
- Give an oral presentation
- Informal in-class report
- Interpret data
- Order items (e.g. strip sequence)
- Participate in discussion
- Peer evaluation
- Post-test
- Pre-test
- Produce a video or video response
- Respond to metacognition/reflection prompt
- Self evaluation
- Solve problem(s)
- Written assignment: One minute paper
- Written assignment: Brochure
- Written assignment: Essay
- Written assignment: Figure and or figure legend
- Written assignment: Lab report
- Written assignment: Literature review
- Other

Lesson Length

- Portion of one class period
- One class period
- Multiple class periods
- One term (semester or quarter)
- One year
- Other

Key Scientific Process Skills

- Reading research papers
- Reviewing prior research
- Asking a question
- Formulating hypotheses

- Designing/conducting experiments
- Predicting outcomes
- Gathering data/making observations
- Analyzing data
- Interpreting results/data
- Displaying/modeling results/data
- Communicating results

Pedagogical Approaches

- Think-Pair-Share
- Brainstorming
- Case Study
- Clicker Question
- Collaborative Work
- One Minute Paper
- Reflective Writing
- Concept Maps
- Strip Sequence
- Computer Model
- Physical Model
- Interactive Lecture
- Pre/Post Questions
- Other

Bloom's Cognitive Level (based on learning objectives & assessments)

- Foundational: factual knowledge & comprehension
- Application & Analysis
- Synthesis/Evaluation/Creation
- Principles of how people learn
- Motivates student to learn material
- Focuses student on the material to be learned
- Develops supportive community of learners
- Leverages differences among learners
- Reveals prior knowledge
- Requires student to do the bulk of the work

Vision and Change Core Concepts

- Evolution
- Structure and Function
- Information flow, exchange and storage
- Pathways and transformations of energy and matter
- Systems

Vision and Change Core Competencies

- Ability to apply the process of science
- Ability to use quantitative reasoning
- Ability to use modeling and simulation
- Ability to tap into the interdisciplinary nature of science
- Ability to communicate and collaborate with other disciplines
- Ability to understand the relationship between science and society

Key Words: List 3 to 10 key words that are relevant for the Lesson (e.g. mitosis; meiosis; reproduction; egg; etc.)

1. biodiversity; DNA; morphology

Scientific Teaching Context

Learning Goal(s)

- *Students will be familiar with the scientific process, from making an observation through communicating their results.*
- *Students will appreciate local biodiversity.*

Learning Objective(s)

- *Students will be able to collect biodiversity samples in the field.*
- *Students will be able to use keys, field guides and microscopy to identify these samples morphologically.*
- *Students will be able to sequence DNA from these samples.*
- *Student will be able to analyze and present the data.*

Introduction

The introduction should provide the origin and rationale for the design of the Lesson and provide enough background information to allow the reader to evaluate the Lesson without referring to extensive outside material. For complex topics, a Science Behind the Lesson article may be simultaneously submitted with the Lesson, so that potential instructors will have sufficient information to implement the Lesson. Do not forget to reference all appropriate sources relating to any part of the Lesson.

The need to improve science, technology, engineering, and mathematics (STEM) education in the United States is widely recognized (1–8). Better programs would engage, retain, and train more students, including from underserved communities, allowing them to meet changing and unfilled market demands and achieve professional aspirations. One area sorely needing improvement is undergraduate biology education, given the rapid changes both in the field and in student body composition. Traditional large lecture classes or outdated laboratory experiences focused on rote memorization of entrenched, disconnected, and outdated concepts fail to adequately prepare many biology students for the complex, multidisciplinary, and technological demands of the competitive and evolving modern world. Many of our increasingly economically and ethnically diverse students are not being updated with respect to novel research and issues, or provided with the cross-disciplinary and critical thinking skills required to handle complex 21st century demands. These range from processing massive amounts of data now available through revolutions in genomics and bioinformatics, to keeping up with breakthroughs in neuroscience, to addressing pressing environmental concerns and developing complex models of climate change (1–3).

To address the issue, the American Association for the Advancement of Science produced *Vision and Change in Undergraduate Biology Education A Call to Action* (2), a unified expert strategy that supports undergraduate research and other evidence-based teaching (EBT) techniques. EBT approaches are those shown through research to improve learning gains (2, 9, 10). They include hands-on, inquiry-based, and student-active methods that are grounded in the scientific process and build critical thinking skills, and other strategies outlined in *Vision and Change.* With current economic trends and skyrocketing private education costs, and despite budget, personnel, facilities, and other limitations, the importance of public institutions offering a low-cost education in this regard is rapidly increasing.

The City University of New York, College of Staten Island (CUNY, CSI). CSI is the sole public higher education provider in this New York City borough. The College offers associates, baccalaureate and master's degrees, and in 2013 enrolled over 13,000 undergraduates. CSI is composed mostly of ethnically diverse, first-generation college students working and/or receiving financial aid, and not yet acculturated to the demands of higher education or STEM. As revealed by the Office of Institutional Research and Assessment, 52% of undergraduates are in their family's first generation to attend college. Students' birth countries include 132 nations. Non-Caucasian ethnicities comprise about 43.5% of the student body, with major ethnic groups of 13.6% African American, 16.4% Hispanic/Latino, and 12.4% Asian/Pacific Islander leading to a US News and World Report ethnic diversity index of 0.54. Most (69.2%) of our full time undergraduates work and receive financial aid (~65% in-state; ~56% out-of-state).

Undergraduate biology teaching at CSI has many strengths, but there are also definite opportunities for improvement through alignment with *Vision and Change*. The yearlong introductory General Biology sequence consists of a lecture and paired lab. At CSI all of the ~670 biology undergraduates are required to take General Biology. With this diverse student body, which encompasses highly variable study habits and attitudes, comes the significant instructional challenge of differentiated learning (11). To assess challenges facing students and faculty, we carried out informal student surveys. Issues needing improvement that were commonly cited by students included: that the lecture courses often contain too much information and details requiring memorization with no cohesive organizing framework, that long PowerPoint lectures and outdated labs do not teach them much, and that the lab and lectures seem disconnected.

A suite of experiences with EBT techniques have led CSI's Biology Department to recognize the motivational power of research and active learning for addressing these issues and enhancing experiences of STEM students. Evolution, the unifying idea that makes sense of biology (12), explains how the world's biota evolved over millions of years and how this shapes today's ecosystems, creating a space to situate humanity within the natural world. Our planet is facing a major biodiversity extinction crisis that is disrupting ecological and evolutionary processes and significantly harming humans and wildlife alike. Evolution's deep-time framework provides a context for understanding biodiversity and human impact on the environment. The framework of evolution gives meaning to biodiversity as something beyond an array of disparate creatures by demonstrating that all of the eclectic and varied forms of life share a common history. The power of evolution to position everyday life as part of the rest of the living world brings out the ecological underpinnings of daily activities, which are often missed by students. Like many other people around the world, CUNY students live in highly urbanized settings, where they are largely disconnected from nature (13). This removal can, in itself, hinder understanding, appreciation, and stewardship of biology and the environment. In this unique lesson we draw on our own expertise with evolution, biodiversity, and conservation to design a program that, complemented by the ethnic and economic diversity of our urban student body, may serve as a case study with applications for other institutions.

Intended Audience

First-year students, biology majors.

Required Learning Time

Three three hour labs sessions.

Pre-requisite student knowledge

General Biology prerequisites such as Math and English.

Scientific Teaching Themes

Active Learning

We will use EBT techniques to meet the objectives outlined above and improve STEM learning gains. These include hands-on, real-world, inquiry-based, and student-active learning methods that incorporate cutting-edge technology, are based on the scientific process, and build critical thinking skills (2, 14–19). In order to make the research more meaningful to students and enhance their learning gains, we will place science in the context of everyday concerns and select local research sites that students can visit (2, 13, 20, 21). Learning gains will be assessed using validated surveys and course observations (22). The proposed objectives are being achieved as follows:

A. *Immerse General Biology undergraduate students in EBT-based classes with biodiversity and evolution research.* Each experimental lecture and lab section of the General Biology sequence will incorporate a research theme framed within a seminal scientific theory illuminating the unity and diversity of living systems. Students will explore the Theory of Evolution by Natural Selection (23, 24) through ecological and genetic characterization of field-collected biodiversity samples. Students will further be exposed to current research pertaining to additional core content topics through CSI faculty presentations, science videos, and/or peer-reviewed publications. Lab and lecture classes will be closely coordinated.

General Biology lab students will be introduced to biodiversity identification through short lectures, discussions, and reading 2 peer-reviewed papers. Each lab section will visit a conservation biology field site, participate in a field experience, take probe measurements, and collect environmental or individual samples for DNA analysis. Working in small groups, each class will then carry out DNA extractions, after which products will be sent out for professional sequencing. Students will then analyze the data in the context of environmental measurements taken in the field (pH, temperature, etc.), and submit a poster for presentation at the CSI Undergraduate Conference. The remaining lab classes, which involve biodiversity surveys, will be grounded in the scientific process. They will also include microscope-based morphological identification of samples collected in the field by the students. In each class, introductory material will be presented and discussed, along with the Methods being used for that survey. Students will formulate and test hypotheses. Results will be obtained, and data discussed.

Assessment

The formal evaluation procedures allow assessment of factors contributing to student success. Student evaluations based on CURE (Classroom Undergraduate Research Experience) (18, 25) surveys will be used. These surveys were designed and validated by Dr. Daniel Lopatto and colleagues to measure learning gains from undergraduate research (18, 25–27). The CURE survey involves pre- and post-tests that evaluate learning gains before and after undergraduate research experiences in the classroom. Sample questions regard plans for graduate education, effects of research experiences on career plans, research experiences, skills gained, and reflections about the scientific process. Additional evaluations will be used to compare experimental and control classes, including course observations (adapted from (22)).

Inclusive Teaching

This project will integrate research and education to address STEM failures in reaching underrepresented groups. Our activities will lead to a more effective and diverse workforce by producing more qualified students. CSI and CUNY have long traditions of engaging students from underrepresented groups, such as women, minorities or persons with disabilities, in education. Many of our students will participate in the research in their classes. Exampls will also be given of diverse scientists. Education, training and dissemination will also be advanced through presentations at professional conferences. The research will be disseminated through websites, research networks, and peer-reviewed publications.

References

1. **Rotherham AJ**. 2011. The Next Great Resource Shortage: U.S. Scientists. Time Mag.

2. **AAAS**. 2011. Vision and Change in Undergraduate Biology Education: A Call to Action. AAAS, Washington DC.

3. **Bialek W, Botstein D**. 2004. Introductory science and mathematics education for 21st-century biologists. Science (80-) **303**:788–790.

4. **President's Council of Advisors on Science and Technology**. 2012. Engage to Excel: Producing One Million Additional College Graduates with Degrees in Science, Technology, Engineering, and Mathematics. Washington DC.

5. **National Science and Technology Council Committee on STEM Education**. 2013. Federal Science, Technology, Engineering, And Mathematics (STEM) Education 5-Year Strategic Plan. Washington DC.

6. **National Research Council**. 2010. Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5. National Academies Press, Washington DC.

7. **National Research Council**. 2011. Expanding Underrepresented Minority Participation : America's Science and Technology Talent at the CrossroadsPublic Policy. National Academies Press, Washington DC.

8. **National Research Council**. 2012. Discipline-based Education Research: Understanding and Improving Learning in Undergraduate Science and Engineering. National Academies Press, Washington DC.

9. **Davies P**. 1999. What is Evidence-Based Education? Br J Educ Stud **47**:108–121.

10. **Mayer RE**. 2011. Applying the science of learning, 1st ed. Pearson, New Jersey.

11. **Tanner K, Allen D**. 2004. Approaches to biology teaching and learning: learning styles and the problem of instructional selection--engaging all students in science courses. Cell Biol Educ **3**:197–201.

12. **Dobzhansky T**. 1973. Nothing in biology makes sense except in the light of evolution. Am Biol Teach **35**:125–129.

13. **Miller JR**. 2005. Biodiversity conservation and the extinction of experience. Trends Ecol Evol.

14. **Buonaccorsi V, Peterson M, Lamendella G, Newman J, Trun N, Tobin T, Aguilar A, Hunt A, Praul C, Grove D, Roney J, Roberts W**. 2014. Vision and change through the genome consortium for active teaching using next-generation sequencing (GCAT-SEEK). CBE Life Sci Educ **13**:1–2.

15. **Woodin T, Carter VC, Fletcher L**. 2010. Vision and Change in Biology Undergraduate Education, A Call for Action - Initial Responses. CBE Life Sci Educ **9**:71–73.

16. **Dolan EL**. 2012. Next Steps for Vision and Change: Moving from Setting the Vision to Change. CBE Life Sci Educ **11**:201–202.

17. **Wei C a, Woodin T**. 2011. Undergraduate research experiences in biology: alternatives to the apprenticeship model. CBE Life Sci Educ **10**:123–131.

18. **Harrison M, Dunbar D, Ratmansky L, Boyd K, Lopatto D**. 2011. Classroom-Based Science Research at the Introductory Level: Changes in Career Choices and Attitude. CBE Life Sci Educ **10**:279–286.

19. **Udovic D**. 2002. Workshop biology: demonstrating the effectiveness of active learning in an introductory biology course. Bioscience **52**:272–281.

20. **Zeidler DL, Sadler TD, Simmons ML, Howes E V.** 2005. Beyond STS: A research-based framework for socioscientific issues education. Sci Educ **89**:357–377.

21. **Gough N**. 2002. Thinking/acting locally/globally: western science and environmental education in a global economy. Int J Sci Educ **24**:1217–1237.

22. **Ebert-May D, Derting TL, Hodder J, Momsen JL, Long TM, Jardeleza SE**. 2011. What We Say Is Not What We Do: Effective Evaluation of Faculty Professional Development Programs. Bioscience **61**:550–558.

23. **Darwin C, Wallace AR**. 1858. On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection. Zool J Linn Soc **3**:46–50.

24. **Darwin C**. 1859. On the Origin of Species. John Murray, London.

25. **Shaffer CD, Alvarez CJ, Bednarski AE, Dunbar D, Goodman AL, Reinke C, Rosenwald AG, Wolyniak MJ, Bailey C, Barnard D, Bazinet C, Beach DL, Bedard JEJ, Bhalla S, Braverman J, Burg M, Chandrasekaran V, Chung H-M, Clase K, Dejong RJ, Diangelo JR, Du C, Eckdahl TT, Eisler H, Emerson J a, Frary A, Frohlich D, Gosser Y, Govind S, Haberman A, Hark AT, Hauser C, Hoogewerf A, Hoopes LLM, Howell CE, Johnson D, Jones CJ, Kadlec L, Kaehler M, Silver Key SC, Kleinschmit A, Kokan NP, Kopp O, Kuleck G, Leatherman J, Lopilato J, Mackinnon C, Martinez-Cruzado JC, McNeil G, Mel S, Mistry H, Nagengast A, Overvoorde P, Paetkau DW, Parrish S, Peterson CN, Preuss M, Reed LK, Revie D, Robic S, Roecklein-Canfield J, Rubin MR, Saville K, Schroeder S, Sharif K, Shaw M, Skuse G, Smith CD, Smith M a, Smith ST, Spana E, Spratt M, Sreenivasan A, Stamm J, Szauter P, Thompson JS, Wawersik M, Youngblom J, Zhou L, Mardis ER, Buhler J, Leung W, Lopatto D, Elgin SCR**. 2014. A course-based research experience: how benefits change with increased investment in instructional time. CBE Life Sci Educ **13**:111–30.

26. **Lopatto D**. 2007. Undergraduate Research Experiences Support Science. CBE Life Sci Educ **6**:297–306.

27. **Lopatto D**. 2004. Survey of Undergraduate Research Experiences (SURE): first findings. Cell Biol Educ **3**:270–277.