Implementation of BioInquiry: A leader course producing perceived learning gains.

Subject/Problem: Lack of student success and retention in STEM fields

Persistence in and success matriculating through science, technology, engineering and mathematics (STEM) curricula is a major challenge for many of today's students (e.g., NRC 1996, 2009) especially those traditionally underrepresented in these fields (AAAS 2011). There is overwhelming evidence that low-income students, women and minorities successfully complete STEM programs based on traditional science curricula at much lower rates than wealthier classmates and white males (e.g., American Council on Education 2006; onal Science Foundation 2007).

The Department of Biological Sciences at Loyola University New Orleans conducted a comprehensive departmental program review in 2013.   This study revealed that retention and graduation rates of Biology majors had declined over the prior two decades (Figure 1). In line with Loyola's mission of promoting social justice, the demographics of the student body have become more diverse in recent years to include more first generation students (generally lower income), women and minorities. This time frame also corresponds to reported changes in how Millennial and GenZ students are reported to learn and interact with information. In order to better meet the needs of Loyola's changing student population we: (1) reviewed the science education best practices literature and met with STEM education and pedagogy experts, (2) conducted a critical review of the Biology major curriculum, and (3) revised and implemented a new first course utilizing high-impact teaching practices, training in fundamental skills and competencies needed by all life scientists, and explicit discussion of the relevancy of the science to students' daily lives.

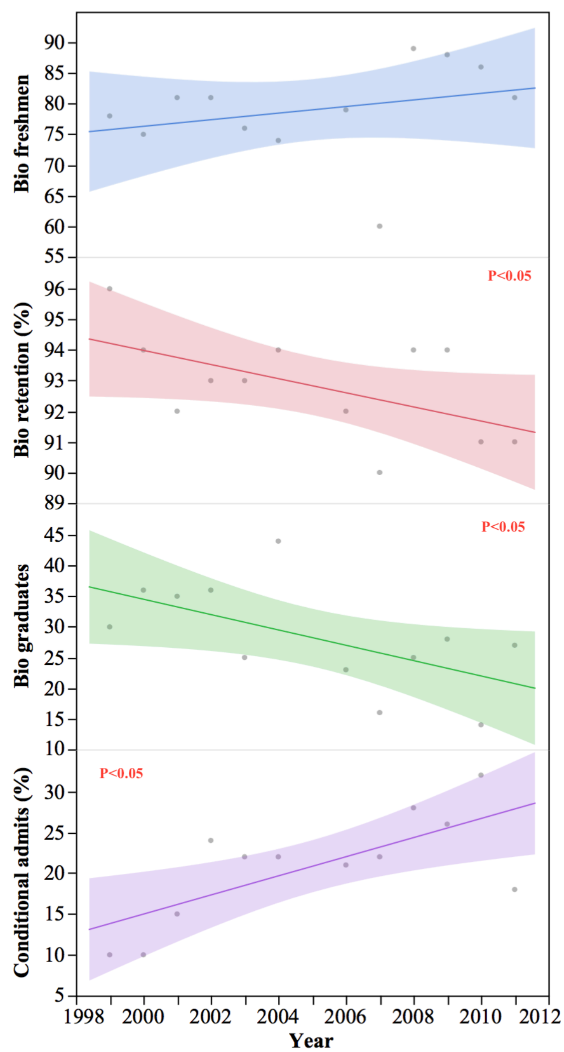

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Figure 1. 2013 comprehensive program review data of Loyola Biology majors.

Our two-year study of best practices (2013-2015) started with the highly influential AAAS document *Vision and Change in Undergraduate Biology Education: A Call to Action* (2011). This important document and further readings of the pedagogical literature by the Biology faculty led to more than a dozen lively meetings during the academic year to discuss the issues raised and two full-day campus workshops facilitated by national STEM education experts. The overarching goal of these meetings, discussions, and workshops was to identify cost-effective and high-impact teaching practices to improve recruitment, retention, and student success. As a department, we recognized the need to restructure the curriculum in order to place a greater emphasis on the development of fundamental scientific skills and competencies at the earliest possible opportunity. These skills and competencies should be reinforced regularly throughout the curriculum and used to explore "real world" problems in biology without sacrificing academic rigor. As noted in *Vision and Change*, "in addition to understanding concepts, undergraduates must have opportunities to develop core competencies to better prepare them to practice biology, as well as to address the complex biology-related issues that our society faces."

Since the challenge to educators outlined in *Vision and Change in Undergraduate Biology Education: A Call to Action* (2011), and previously with NRC's *BIO2010: Transforming Undergraduate Education for Future Research Biologists* (2003) (among other influential publications), many institutions have published success stories of transformation of courses and curricula that have improved their students' attitudes (e.g., Kowalski et al. 2016; Olimpo et al. 2016) content knowledge and motivation (e.g., Olimpo et al. 2016), students' perceived understanding of the scientific process (e.g., Kowalski et al. 2016), and graduation rates and degree completion (e.g., Rodenbusch et al. 2016). These transformations, in particular, have included the implementation of classroom/course-based undergraduate research experiences (CUREs) into the curriculum. This form of active learning affords benefits to the students by providing them hands-on, novel research experiences and to the faculty by allowing oversight of multiple research projects during a given class time.

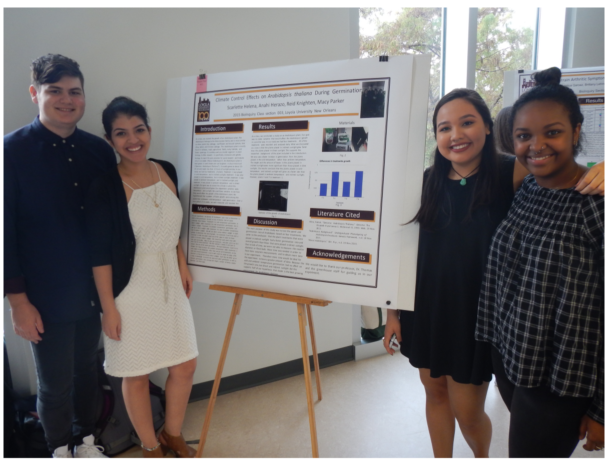
Relatively small, first-semester leader courses, engaging students in the process of scientific inquiry have proven to be one of the most effective and high-impact educational practices available. An emerging trend in STEM education is to implement discipline-specific leader courses that introduce first-semester college students to the skills and competencies needed to promote long-term academic success within the major (e.g., Goldeye et al. 2012). These leader courses focus on one or a few exciting topics or themes rather than superficially covering a large number of topics. We adopted this model and have implemented a semester-long first course, BioInquiry, which emphasizes development of the skills and competencies important for student learning outcomes associated with success in biology (Table 1). BioInquiry engages students in the process of scientific inquiry while providing a framework for academic success. Students collaborate to design experiments, apply quantitative reasoning to their results, and learn scientific communication while exploring a theme that instills awareness of the interdisciplinary nature of biology and its relationship to society. BioInquiry reinforces major biological concepts while actively engaging students in the process of scientific discovery *during their very first semester*. This course also intentionally builds a sense of community among incoming Biology majors and seeks to support the diverse backgrounds and educational needs of each student.

Table 1. BioInquiry student learning outcomes (skills and competencies)

Students will apply critical thinking skills to the experimental design process.
Students will demonstrate introductory level scientific communication skills.
Students will demonstrate basic level information literacy.
Students will demonstrate a working knowledge of selected core concepts in biology.
Students will learn to compassionately engage with the world.

Students will demonstrate knowledge of resources and practices that will support academic success in biology.

Since the implementation of BioInquiry in 2015, four different course themes have been developed. All course sections share a common framework of assignments, scientific skills, and student learning outcomes, while the theme of each section is determined by the research expertise and interests of the instructor. For example, one section examines arthritis as a major cause of disability and as an emerging target for personalized medicine. Scientific concepts are introduced by investigating the structure and function of joints as well as the tissues and cell types involved in arthritis. Discussions and collaborative experiments highlight environmental, genetic, and molecular factors that contribute to disease. In each of the developed courses, students gain hands-on experience with research methods and engage in the process of discovery through group investigations. BioInquiry culminates with a collaborative research project and student poster session (Figures 2,3).



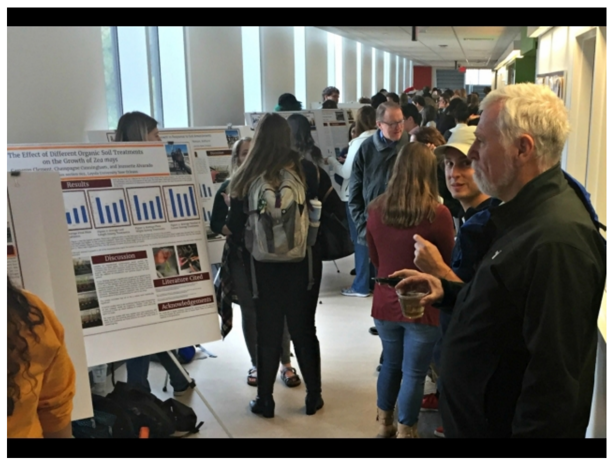


Figure 2. BioInquiry students proudly display their research. Figure 3. BioInquiry poster session.

Importantly, these skills and competencies are being reinforced throughout the curriculum so that all students taking Biology courses will benefit. For example, our Cells and Heredity lab now includes iterative writing assignments, peer review, and statistical analyses. New and enhanced electives utilize active learning strategies and reinforce scientific skills. For example, in Parasitology, students work with original research data "discovering" the blood sources of the kissing bugs in New Orleans in a simple bioinformatics exercise and comparing the genetic diversity and structure of kissing bug populations from Bolivia and New Orleans, and mapping the diversity onto topographical maps to understand drivers of population subdivision. And in our Animal Behavior course, students conduct novel research on spider communities in a local national park. They then use statistical software to analyze the data and write a scientific paper about the experiential learning lab. In these courses data analysis, interpretation, collaborative and scientific communication skills are practiced and reinforced. Thankfully textbook publishers have integrated active learning, scientific skills and relevant content into Biology textbooks. In our second core course, Cells and Heredity, we make extensive use of these resources and require chapter study and online homework (such as Mastering Biology) that includes scientific skills and current news examples before the content is covered in class.

Design or Procedure:

This study analyzing the impact of our new BioInquiry leader course was conducted over three years (Fall 2015-Fall 2017) and included 154 declared biology majors enrolled in this course. Three biology faculty taught a total of 11 sections during the study period. The average class size was (20, min 8, max 24). The class was scheduled as two 75 minute meetings per week. The majority of the course content was consistent from section to section other than the biology content used to teach the scientific process skills. We used in-class assignments to assess student learning in experimental design, quantitative reasoning, data analysis and visualization, scientific communication, information literacy and collaboration. In addition, we developed and implemented a Student Assessment of Their Learning Gains (SALG) survey to provide a pre and post student-centered assessment. The SALG is a free evaluation tool that allows faculty to gather "learning-focused feedback from students" (https://salgsite.net). Finally, we evaluated temporal changes in grades, retention, and graduation in BioInquiry and other core and elective Biology courses as part of overall assessment of the Biology curriculum. This paper will focus on the results of the SALG data.

During the first and final weeks of the fall semester, students enrolled in this experimental class responded to the SALG survey consisting of questions ranging from basic biology content to process of science skills, attitudes, and integration of science into learning (Figure 4). Credit was given to encourage participation. Analyses of variance (ANOVA) were used to determine if there were significant differences in responses to each question pre and post course and among years.

Scale: 1 - NA 2 – not at all 3 – just a little 4 – somewhat 5 – a lot 6 – a great deal

1. Presently, I understand how scientific research is carried out.
2. Presently, I can make an argument using scientific evidence.
3. Presently, I am interested in taking additional biology courses after this one.
4. Presently, I am in the habit of discussing science-related civic or political issues informally.

Figure 4. Sample of SALG questions students completed at beginning and end of course.

Analyses and Conclusions:

Students significantly increased their perceived understanding of all 15 content questions and all 9 process skills questions (Table 2).

Table 2. Subset of questions used on SALG surveys given at beginning and end of semester. Most student responses using a six -point scale ranging from 1 (do not agree) to 6 (agree a lot) increased significantly (ANOVA, $P<0.05$) in the second survey. Ns indicates not significant.

UNDERSTANDING: *Presently, I understand...*	%
How scientific research is carried out	21.6%
The science behind important scientific issues in the media	21.1%
The distinction between a hypothesis and a theory	8.7%
What constitutes "good" science	24.6%
How life-forms have evolved over time	9.0%
The basic units of biological structures that define the functions of all living things.	9.6%
The influence of genetics on the control of the growth and behavior of organisms.	9.3%
The ways in which chemical transformation pathways and the laws of	15.3%
The ways in which living things are interconnected and interact with one another.	9.3%
The impact of arthritis on society.	38.9%
The basic anatomy of the knee joint.	37.8%
The risk factors for developing arthritis.	44.6%
The tissues, cells, and molecules that change during arthritis.	46.3%
Current treatments for arthritis.	43.6%
How research could lead to new and improved treatments for arthritis.	48.5%
SKILLS: *Presently I can...*	
Think critically about scientific findings I read about in the media	15.4%
Determine what is -- and is not -- valid scientific evidence	16.0%
Make an argument using scientific evidence	15.7%
Interpret tables and graphs	8.3%
Understand mathematical and statistical formulas commonly found in scientific texts	16.4%
Distinguish between primary and secondary literature	21.4%
Extract main points from a scientific article and develop a coherent summary	17.4%
Pose questions that can be addressed by collecting and evaluating scientific evidence	18.1%
Identify bias in information about science	17.2%
ATTITUDES: *Presently, I am...*	
Interested in discussing biology with friends or family	ns
Interested in reading about biology and its relation to civic issues	ns
Interested in reading articles about biology in magazines, journals or on the internet	ns
Interested in taking additional biology courses after this one	ns
Interested in exploring career opportunities in biology	ns
Interested in joining a biology club or organization	ns
Interested in attending a health professional school (e.g., Medicine, Dentistry, PT,	ns
Interested in attending graduate school in a biology-related field	ns
Interested in teaching biology	11.6%
INTEGRATION OF LEARNING: *Presently, I am in the habit of...*	
Discussing science-related civic or political issues informally	6.8%
Reading science-related magazines not required by class	6.1%
Writing letters or emails to public officials about science-related civic or political	7.5%
Debating or offering public comment on science-related civic or political issues	ns
Writing a letter to the editor about science-related civic or political issues	7.2%

Persistence (retention) data after one-year following completion of Bioinquiry indicate an upward trend in the major and overall at Loyola (Figure 5). Furthermore, fewer students are not only leaving the University, but fewer are leaving the major as well (Figure 6). Anecdotally, many have reported in faculty meetings that lab reports, including statistics and overall understanding of experimental design, has improved dramatically since the implementation of BioInquiry.

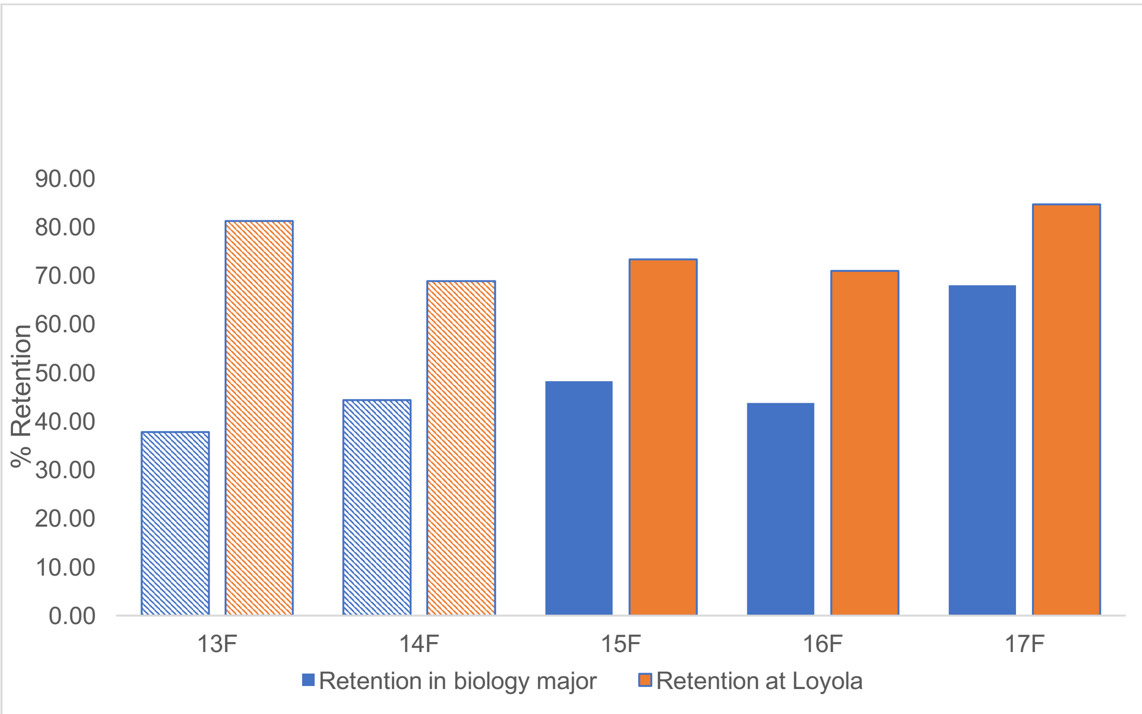
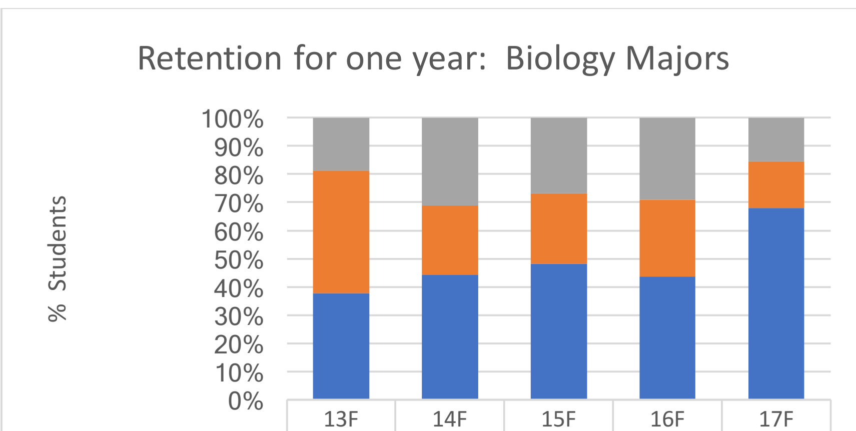


Figure 5. Percent retention data after one-year following completion of Bioinquiry.



	13F	14F	15F	16F	17F
Departed Loyola	18.84	31.15	26.79	29.17	15.38
Changed majors	43.48	24.59	25.00	27.08	16.67
Persisted as biology majors	37.68	44.26	48.21	43.75	67.95

Figure 6. Percent student retention data after one-year following completion of Bioinquiry.

Contribution:

Student success and matriculation in STEM fields, particularly Biology, is important for many reasons, namely to produce health care professionals, research scientists, industry, and educational professionals in the discipline. In addition, to remain competitive internationally in STEM fields, we must prepare our graduates with skills necessary for success. Leader courses focusing on the process of science rather than detailed content have been successful at other institutions and so far, our results support this as well.

References:

AAAS (2011). Vision and Change in Undergraduate Biology Education: A Call to Action. Washington, DC: AAAS. Available online at http:// visionandchange.org/finalreport/.

American Council on Education. (2006). Increasing the Success of Minority Students in Science and Technology. Washington, D.C.: American Council on Education.

Goldey, ES, CL Abercrombie, TM Ivy, DI Kusher, JF Moeller, DA Rayner, CF Smith, and NW Spivey (2012). Biological inquiry: a new course and assessment plan in response to the call to transform undergraduate biology. CBE-Life Sciences Education 11.4:353-363.

Kowalski, JR, GC Hoops, and RJ Johnson (2016). Implementation of a Collaborative Series of Classroom-Based Undergraduate Research Experiences Spanning Chemical Biology, Biochemistry, and Neurobiology. CBE-Life Sciences Education 15.55:1-17.

National Research Council (NRC) (1996). From Analysis to Action: Undergraduate Education in Science, Mathematics, Engineering, and Technology, Washington, DC: National Academies Press.

NRC (2003). BIO2010: Transforming Undergraduate Education for Future Research Biologists, Washington, DC: National Academies Press.

NRC (2009). A New Biology for the 21stCentury: Ensuring the United States Leads the Coming Biology Revolution, Washington, DC: National Academies Press.

National Science Foundation. (2007). Women, Minorities, and Persons with Disabilities in Science and Engineering. Arlington, Va.: National Science Foundation.

NGSS Lead States (2013). Next Generation Science Standards: For States, By States. Washington, DC: The National Academies Press.

Olimpo, JT, GR Fisher, and SE DeChenne-Peters (2016). Development and Evaluation of the Tigriopus Course-Based Undergraduate Research Experience: Impacts on Students' Content

Knowledge, Attitudes, and Motivation in a Majors Introductory Biology Course. CBE-Life Sciences Education 15.72:1-15.

Rodenbusch SE, PR Hernandez, SL Simmons and EL Dolan (2016). Early Engagement in Course-Based Research Increases Graduation Rates and Completion of Science, Engineering, and Mathematics Degrees. CBE-Life Sciences Education 15.20:1-10.

SALG. Student Assessment of Their Learning Gains. Retrieved from https://salgsite.net on June 14, 2018.