ABSTRACT

Introduction and Initial Analysis of the Ciliate Investigative Learning Initiative Classroom-Based Undergraduate Research Experience

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Due to inherent shortcomings in the traditional laboratory structure, inquiry-based laboratories have increasingly been adopted to increase student engagement in science and provide an early research experience. At Baylor University, a new inquiry-based introductory biology laboratory, the Ciliate Investigative Learning Initiative Classroom-Based Undergraduate Research Experience (CILI-CURE), has been designed to address these learning goals. In this study, the first group of student outcomes from this initiative are evaluated by the Test of Scientific Literacy Skills, Course-Based Undergraduate Research Experience Survey, and the Baylor Course Evaluation. Statistical analyses indicate significant gains in students' skills in data analysis, accessing primary literature, identifying the validity of scientific arguments, collecting data, and learning laboratory techniques. While supporting the concept that inquiry-based courses improve students' perception of science, thus providing an improved way to teach the process of science, these outcomes also indicate areas for improvement in qualitative skills.

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INTRODUCTION AND INITIAL ANALYSIS OF THE CILIATE INVESTIGATIVE LEARNING INITIATIVE CLASSROOM-BASED UNDERGRADUATE RESEARCH EXPERIENCE

A Thesis Submitted to the Faculty of

Baylor University

In Partial Fulfillment of the Requirements for the

Honors Program

By

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Waco, Texas

May 2017

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CHAPTER ONE

Introduction

In recent years, science education literature has emphasized the impact of teaching style and course design on student learning outcomes. Inquiry-based and discovery-based courses have become the new standard of quality classroom organization, and explicit instruction on the learning process has become increasingly common. Current educational research indicates a need for substantial changes in course curriculum, including a reworking of traditional science classroom configuration (Bauerle et al., 2011). In order to increase student engagement in STEM fields and provide the highest quality education, a new inquiry-based curriculum is introduced for Baylor University's Modern Concepts of Bioscience 1 Laboratory (BIO 1105). This study introduces and evaluates the Ciliate Investigative Learning Initiative Classroom-Based Undergraduate Research Experience (CILI-CURE) on the basis of content, student experiences, and student ability to interact with scientific ideas.

Background

Within the realm of education research, there are a variety of definitions of inquiry-based learning. Although there is a general consensus that inquiry-based learning requires allowing students to engage in the discovery process, the type and degree of discovery involved is highly variable from one case to the next (Weaver, Russell, & Wink, 2008). Rather than drawing arbitrary distinctions between these types of lab, Weaver described inquiry-based learning as a sliding scale ranging from courses with low student responsibility to high student responsibility (Figure 1)(2008). Following Weaver's scale, the style of discovery in the inquiry-based BIO 1105 course is best described as guided inquiry or open inquiry (hereafter referred to as inquiry). This style of laboratory activity provides the initial problem and basic concepts, but guides the students while they formulate and examine questions, plan and carry out procedures, and gather and analyze results (Gormally, Brickman, Hallar, & Armstrong, 2009). This type of inquiry allows a greater level of structure than actual undergraduate research, which makes large student groups more feasible and makes the course more accessible for all students, regardless of background.

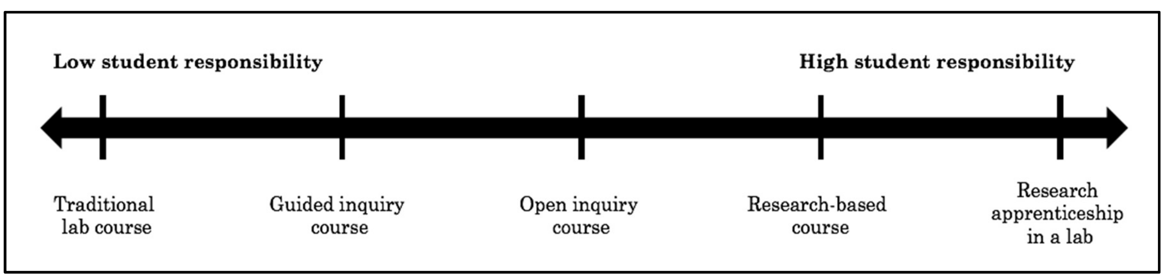


Figure 1: Adapted from Weaver et al., 2008. This figure displays the spectrum of free inquiry that can exist in a laboratory course.

The benefits of inquiry-based education are numerous, but are accompanied by some challenges. Current research indicates that students in inquiry-based courses develop higher-level thinking skills, maintain a deeper understanding of the subject matter, feel realistically confident about their ability to understand and participate in science, and have a better understanding of scientific knowledge and its uses (Weaver et al., 2008). In addition, the active learning that is integral to inquiry-based learning particularly benefits student populations that are underrepresented in STEM fields, including females and ethnic minorities. The focus on interdisciplinary problems in inquiry-based learning has also been hypothesized to better prepare students for life beyond the college classroom. (Sanders et al., 2016).

Probably the most universal challenge of inquiry-based learning is the process of building a curriculum that can be implemented successfully on a large scale. Although there are inquiry-based scientific lab programs at numerous universities across the country, most of these programs only accept a small cohort because the curriculum is too expensive, time-consuming, or academically rigorous to be implemented for larger groups (National Academies of Sciences, Engineering, and Medicine, 2015). While these are legitimate concerns for anyone designing an inquiry-based curriculum, they do not negate the possibility of successfully designing such a program. Programs such as Purdue University's Center for Authentic Science Practice in Education (CASPiE) and the University of Texas at Austin's Freshmen Research Initiative (FRI) exemplify the fact that inquiry-based curricula can be successfully implemented on a large scale. Since its opening in 2004, CASPiE has resulted in the creation of five undergraduate research centers and has involved over 6000 students at 17 different institutions. In 2014, FRI reported involving more than 800 freshmen chemistry students in cutting-edge research (National Academies of Sciences, Engineering, and Medicine, 2015). Both of these programs have been established for over ten years, indicating that these large-scale programs can be successfully maintained for the long term.

At Baylor University, the current BIO 1105 course is a traditional lab course, featuring separate laboratory activities meant to highlight individual concepts covered in the corresponding introductory biology lecture. Students acquire and memorize discrete pieces of knowledge, and are evaluated on the basis of their ability to recite this information on three multiple-choice exams and practicals. While this course introduces students to basic laboratory techniques such as light microscopy and Gram-staining, it fails to emphasize the applications of these techniques or give students realistic situations in which to apply them. Students experience laboratories in which the process is dictated and the outcome is highly predictable, which is often not the case in real research settings. While the multiple-choice tests act as summative assessments, they often do not require critical thinking. In addition, the lack of ongoing formative assessments reduces the opportunity for student growth.

Instruction is delivered by the pages of a textbook and lectures from graduate students, and is not adjustable to the needs and interests of the students.

The defined academic goals of Baylor University, the Baylor College of Arts & Sciences, and the Baylor Department of Biology of providing a transformational education support the revision of this curriculum. Existing inquiry-based courses at Baylor are the model for this revision, including the Wetlands Biology course taught by Marty Harvill and the Science Education Alliance Phage Hunters Advancing Genomics and Evolutionary Science (SEA-PHAGES) taught by Tamarah Adair. The Wetlands Biology course was established in 2009 and is a one-semester program for 48 students. Within this semester, students are tasked with creating, testing, and evaluating a hypothesis at the Lake Waco Wetlands, artificial wetlands bordering the North Bosque River. The SEA-PHAGES course at Baylor is part of a larger program established at dozens of universities across the country, and has been active at Baylor since 2010 (Jordan et al., 2014). This program is two semesters long and accepts 24 freshmen students a year, focusing on microbiology. More specifically, SEA-PHAGES students study the bacteriophage that have hosts in the *Actinobacteria* phylum. Students identify, isolate, and characterize phages found in the soil, ultimately annotating the phage genomes and submitting their information to the Science Education Alliance's database. Both of these courses focus on engaging students in ongoing research. This setup provides students the opportunity to not only succeed in the lab and classroom, but also to continue in research and scientific thought beyond their freshmen year.

Courses such as the Wetlands project and SEA-PHAGES are not only valuable to the students participating in them, but also work to fulfill long-term goals on the institutional level. Baylor's University Vision, *Pro Futuris*, calls for transformational educational experience, interdisciplinary and compelling scholarship, community engagement, and stewardship of the environment. The College of Arts and Sciences' strategic plan to enact *Pro Futuris*, ASPIRE, specifically identifies new strategies of engaged learning as essential to the effort to provide a Liberal Arts education in modern society (Baylor University College of Arts & Sciences, 2014). Courses such as SEA-PHAGES and Wetlands Biology respond to these goals by engaging students in research early in their educational experience and giving them the opportunity to become part of the scientific community. Since inquiry-based learning is the new standard to truly engage students and these courses not only involve inquiry but ongoing research, these criteria are fulfilled as well. In addition, a required freshmen research-based lab naturally advances the Baylor University Department of Biology's goal to create a community of learners and culture of discovery, and explicit instruction on the nature and value of science reinforces the Department's emphasis on the role of biology in society.

Course Design

The CILI-CURE lab aims to discover and characterize soil ciliates, single-celled organisms that are characterized by the presence of two types of nuclei, extensive cilia, and complex cell reproduction. Ciliates were chosen because they are common in the environment, safe to grow in culture, and include a well-established model organism. These organisms also play a role in ordering the bacterial soil communities and stimulating nitrification and ammonification. Ciliates have been described as biological regulators whose presence is vital to the maintenance of healthy soil (European Comission, 2010). Therefore, ciliates are useful in approaching biological concepts from a molecular and cellular approach and a systems approach. However, the understanding of the diversity and functioning of these industrious organisms is seriously limited. There are currently over 8000 identified species of soil ciliates, and the estimated number of true biological species is estimated to be two to three times greater (Lynn, 2009).

Since information on soil ciliates is largely limited to a few well-known model organisms and soil samples are easily obtained, this topic is inexpensive, unique, and provides students the opportunity to add to the body of existing knowledge. Ciliates are highly varied and simple to collect and observe, which gives students the opportunity to think critically and acquire basic laboratory techniques. Following the successful model set by SEA-PHAGES and the Wetland project, this lab gives groups of students the opportunity to set up and evaluate experiments, giving them ownership of their projects while exercising critical thinking skills. This topic is also easily paired with explicit discussion on scientific literature, the nature of science, learning theory, and the role of biology in society. While this project does not yet have the infrastructure of the SEA-PHAGES program, there is room for eventual expansion and collaboration, as well as additional research and publication.

In addition to the style of teaching, the new BIO 1105 course is unique in that explicit instruction on the nature of science and learning theory is built into the course structure. Although success in traditional introductory life science laboratories requires the acquisition of discrete pieces of knowledge and repetition of basic laboratory skills, these types of laboratory exercises rarely require in-depth thinking and often give an unrealistic image of scientific experimentation (Domin, 1999). By coupling hands-on experience with scientific concepts and laboratory methods with instruction on the nature of science, this course gives students a more authentic experience as well as a strong foundation for their future interactions with STEM materials. While inquiry-based learning is often credited with more sophisticated development of students' understanding of how science operates, educational research shows that these types of gains are only seen when the nature of science is explicitly discussed in the course (National Academies of Sciences, Engineering, and Medicine, 2015) (Yacoubian & BouJaoude, 2010). Thus, it is important that the instruction on the nature of learning, science, and scientific literacy should be explicit as well as integrated in the subject matter itself in a well-developed course.

This course emphasizes scientific logic and reasoning skills rather than recollection of scientific facts. To differentiate these two types of learning, Gormally et el. described them as “derived” and “fundamental” scientific literacy skills (2009). Rather than adhering to a transmissionist view of learning and requiring students to learn and repeat specific “fundamental” scientific facts, a course focusing on “derived” scientific literacy skills emphasizes higher-level thinking and life-long skills. Adhering more closely to a constructivist view of learning, the concept of derived scientific literacy skills focuses on students’ ability to analyze and evaluate scientific information. CILI-CURE lab activities challenge students to utilize creativity and existing knowledge to design and carry out experiments, and allow students to develop a firsthand understanding of soil communities by making detailed observations.

The nature of the CILI-CURE course increases the importance of discussing and developing derived scientific literacy skills. BIO 1105 is an introductory biology course that is a requirement for most science majors, and is most often taken in the first or second year of their undergraduate career. For many students, this course and its partner (BIO 1106) is their first exposure to college-level science laboratories. Thus, it is particularly essential that the curriculum can effectively prepare students to be scientifically literate citizens, whether or not they choose to pursue more coursework in STEM fields.

Course Overview

The Ciliate Investigative Learning Initiative Classroom Undergraduate Research Experience (CILI-CURE) follows a blended classroom model, where class time is used to cement and expand upon learning that was initiated outside of the classroom. This new curriculum uses the learning management system Canvas to deliver pre-lab activities that discuss lab techniques, scientific thinking, and learning theory. Each lab meeting begins with a short (10-15 minute) lab lecture crafted to further develop the concepts introduced in the pre-lab and make connections between lab procedures, lab activities, and core biological concepts. After completing the lab procedure for that day, students are instructed to take 10 minutes to discuss "Questions That Matter" with their group of two to three other students. After the group discussion, each student writes down their thoughts and turns them in for lab credit. Not only do these questions continue to develop themes introduced in the pre-lab and lab lecture, but they give students the opportunity to discuss current issues in the field of biology and to realize that not every question can have a single definite answer.

Assessments in the CILI-CURE course are focused on authentic process-of-science skills, such as writing scientific reports, preparing oral presentations, maintaining laboratory notebooks, and creating scientific posters (Appendix A). In addition, all assessments are formed to give constructive feedback to students throughout the course of the semester that will help them hone these skills. In contrast to this is the traditional BIO 1105 course, which uses three multiple choice exams spaced throughout the semester to measure student outcomes without really giving students constructive feedback or equipping them to grow as scientific thinkers. In addition, the activities for the CILI-CURE and traditional BIO 1105 courses are quite dissimilar. Although both courses teach a similar number of laboratory techniques, the CILI-CURE course builds upon each technique with each lab period, often requiring students to use techniques taught previously in new ways. It is clear how each technique and each lab activity is moving the experiment forward towards larger goals. The traditional BIO 1105 course teaches many valuable techniques, but they are largely distinct from one another, and there is very little overlap from one lab session to another. Once learned, a lab technique may never be used again in the class. In addition, lab activities in CILI-CURE tend to be more independent and open-ended than those in the traditional BIO 1105 course.

A final significant difference between the traditional BIO 1105 course and the CILI-CURE course are the learning objectives for each curriculum. While the traditional BIO 1105 course has wide-spread learning objectives that correspond to many important concepts in biology, they are often obscured within the specific, step-by-step instructions of each lab activity. The learning objectives are often highly specific to each activity, and can fail to connect the specific activities to bigger biological concepts. CILI-CURE learning objectives are clearly linked to certain activities, and students are directly reminded of them in their pre-lab activities, lab lectures, and Questions That Matter. Although the CILI-CURE course focuses on a very specific group of organisms, students are regularly reminded of the connections to larger biological concepts and are challenged to learn deeply. In addition, CILI-CURE objectives include concepts not solely restricted to the biological subject matter, including ideas about the nature of science and learning theory.

The CILI-CURE course can be differentiated into two main sections – an experimental design period and a discovery period. For the first part of the semester, students work with known ciliate cultures and develop basic biology lab skills such as making solutions of a known concentration, pipetting, and using light microscopes. Over a period of several weeks, each group of students design and carry out a controlled experiment on the model organism *Tetrahymena pyriformis*. While testing variables such as temperature, aeration, culture media, and the presence of environmental toxins, students learn about experimental design, data presentation, basic lab techniques, and are introduced to scientific literature. In addition, this experimental design portion focuses on the systems view of biology, encouraging students to make connections between their deep understanding of the model organism with the broader ideas of global ecosystems. While learning extensively about the single model organism, students are challenged to look to the scientific literature for additional information, make connections to primary research, and ultimately understand the importance of using controlled experiments to approximate the workings of complex systems. At the end of the first portion of the semester, each student turns in a scientific lab report that walks through the reasoning behind the experiment, experimental design, techniques, results, and conclusions. This project also focuses on using primary scientific literature to establish the hypothesis, understand the results, and put outcomes into a larger context.

The second portion of the course walks the students though the process of isolating, culturing, and characterizing ciliates from a soil sample. Whereas the first part of the semester follows the familiar 'scientific method' of carrying out a controlled experiment to examine a hypothesis, the second part of the course immerses the students in open-ended scientific discovery and gives students further ownership of their own work. As students follow their soil samples through the process of collection, soil analysis, and culturing and characterizing ciliates, they engage deeply in the diversity of life and experience the joys and frustrations of open-ended experimentation. At the conclusion of the semester, each student will have ideally isolated, cultured, and characterized at least one unique ciliate from their soil sample.

Characterization is tentatively determined by morphological and behavioral observation and confirmed via extraction of cellular DNA, and amplification and sequencing of the 18S rRNA gene. For their final project, each group of 3-4 students compile their results and present them in the form of a scientific poster. As students apply scientific techniques to isolate and archive a potentially unique ciliate, they develop a deep understanding of soil ciliates, their importance to the soil ecosystem, and their relevance to ecosystems and society.

Throughout the semester, students maintain both a physical laboratory notebook and an online blog. In addition to maintaining the organized recording aspect of a physical laboratory notebook, an online laboratory notebook has the advantages of encouraging unstructured collaboration between students and allowing students to post photographic evidence. The online format allows instructors easy access and an efficient means of monitoring the notebooks of many students.

The specific purpose of this thesis is to analyze the learning outcomes of students in the CILI-CURE course during the fall of 2016 based on three different assessment tools. This analysis was structured to evaluate the efficacy of the CILI-CURE curriculum in terms of changes in students' process of science skills and attitudes towards science.

CHAPTER TWO

MATERIALS AND METHODS

The success of CILI-CURE was evaluated by three main methods, each measuring a different aspect of the course outcomes. The first analysis tool, the Test of Scientific Literacy Skills (TOSLS), was established in 2012 and measures student outcomes in terms of their gains in derived scientific literacy skills (Gormally, Brickman, & Lutz, 2012). The second tool used was the Classroom Undergraduate Research Experience (CURE) Survey, which measures changes in students' attitudes towards science before and after their CURE experience (Lopatto et al., 2008). Finally, the Baylor Course Evaluation gives opportunities for specific feedback about course structure. All three tests were administered online and student participation was encouraged by offering a few extra credit points in the course. These surveys were considered IRB exempt since they were optional and took place within the context of the teaching laboratory. The combination of these three means of measurement were used to provide a comprehensive look at student outcomes, identifying both strengths and weaknesses of the curriculum.

Demographics

This 15-week course was implemented during the Fall 2016 semester with a group of 29 students, a typical size for BIO 1105 courses. The students for the course were recruited from the same BIO 1305 lecture course, so they all received the same biology lecture and assignments outside of lab. All students in a single lecture course were notified by email about the opportunity to participate in a research-based laboratory course, and those who responded positively were given a permit to enroll. Demographic information of gender, ethnicity, and student classification was collected using the CURE Survey.

Test of Scientific Literacy Skills Survey

The Test of Scientific Literacy Skills (TOSLS) was developed to measure students' ability to utilize scientific literacy skills in solving problems (Gormally et al., 2012). A representative group of 13 of the original 28 TOSLS questions were administered as a pre- and post-test to evaluate student growth (Appendix B). The 13 questions selected correspond to the nine derived scientific literacy skills established by the TOSLS: (1) identifying a valid scientific argument, (2) using primary literature, (3) evaluating appropriate uses of scientific information, (4) understanding research design, (5) making graphs, (6) interpreting graphical representations, (7) using quantitative skills, (9) understanding basic statistics, and justifying predictions based on data (Appendix C). Students who took both the pre- and post-test were included in the analysis to compare the changes within each student, per question, and per skill. The changes in scores were evaluated for significance using a paired t-test.

Classroom Undergraduate Research Experience Survey

Where the TOSLS evaluated student growth in derived scientific literacy skills, the Classroom Undergraduate Research Experience (CURE) Survey was crafted to measure students' attitudes towards science (Lopatto et al., 2008). The CURE Survey was also administered as a pre- and post-test to all students who took BIO 1105 in the fall semester (Appendix D, Appendix E). The questions of the CURE survey can be grouped into three main lines of inquiry – students' attitudes towards science, the experience students gained in the course, and the benefits they identified from their laboratory experience.

Baylor Course Evaluation

The third means of assessment of this course were the course evaluations that Baylor administers at the end of every semester (Appendix F). Whereas the TOSLS and CURE are designed to evaluate changes in student ability and attitude, the course evaluation gathers feedback on the course itself. This evaluation also asks more open-ended questions, gaining insight on student perspective.

CHAPTER THREE

Results

Demographics

Twenty-nine students were enrolled in the inquiry-based section of BIO 1105 in the fall of 2016. Based on demographic information from the CURE survey, a large majority of these students were first-year university students (76%), a smaller percentage were in their second year (21%), and one individual was a third-year university student (3%). This is fairly typical of the enrollment in all BIO 1105 sections, which CURE Survey data from the fall of 2016 indicates are 87% first-year students, 10% second-year students, 2% third-year students, and < 1% fourth-year students.

Within this group, twenty students (69%) were female and nine students were male (31%). This is reflective of the majority female population of Baylor University as a whole and the Biology department in particular. Data from the fall of 2016 indicates that enrollment in all BIO 1105 sections was 65% female and 35% male.

In regards to ethnicity, the majority of students in this course identified as White (71%), with smaller groups identifying as Hispanic/Latino (14%), African American (10%), Asian American (5%), and other (5%). These are again fairly representative of the total enrollment in BIO 1105 in the fall of 2016, with a slightly higher percent of white students than standard. The ethnic makeup of the BIO 1105 student population for the fall of 2016 was 61% White, 15% Hispanic, 10% Asian American, 8% African American, 2% Filipino, 1% American Indian, and 4% other.

Test of Scientific Literacy Skills Survey

Of the 29 students in the course, 24 students completed both the TOSLS pre-test and post-test and were included in this analysis. There was an overall improvement of approximately 9.62% between the pre-test and post-test for the class, which was significant at the $p < 0.01$ level when evaluated using a paired t-test. Of the 24 students analyzed, 15 individuals had a net positive change on their score, representing 63% of those surveyed (Figure 2). Four students (17%) had no net change, and five students (21%) had a net negative change. When broken down by gender, males had a higher average improvement (11.54%) than their female peers (8.65%). However, when evaluated using a pooled t-test, this difference was not significant at the $p < 0.1$ level.

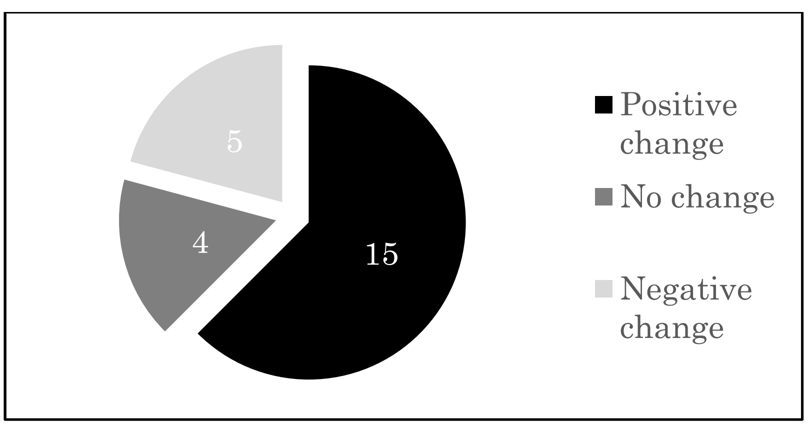
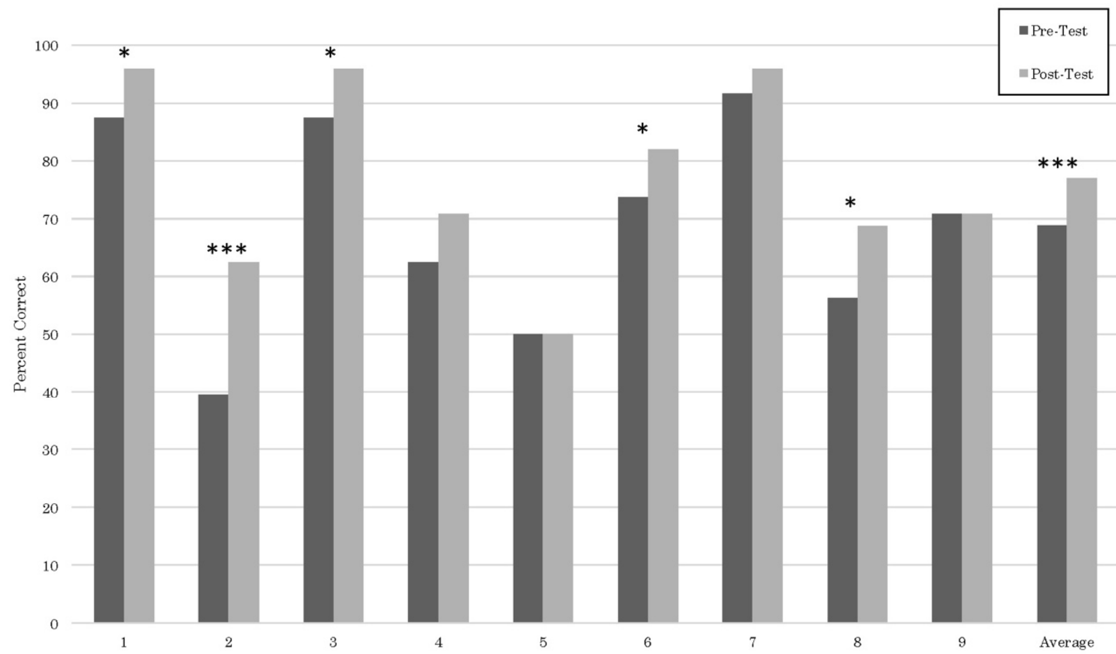


Figure 2: Breakdown of TOSLS student changes between pre- and post-test.

When TOSLS results were broken down by question, ten of the thirteen questions had an overall positive change, and seven had significant gains at the $p < 0.1$ level. The highest improvements were seen on questions two (+25.0%), seven (+20.8%), and nine (+25.0%), which were all significant at the $p < 0.025$ level. Questions eight and 13 had no net change, and question six had a net negative change that was not significant at the $p < 0.1$ level.

When the questions were grouped according to the nine TOSLS scientific literacy skills, there was an average improvement of 8.1% for the class, which was significant at the $p < 0.01$ level (Appendix C, Figure 3). Of the nine skills, seven showed an improvement and five of these were significant at the $p < 0.1$ level. The greatest improvement was seen in skill 2 (+22.9%, $p = 0.006$), which addresses the students' ability to evaluate source validity and distinguish types of sources. Less significant gains were seen in the skills of identifying a valid scientific argument (+8.3%, $p = 0.08$), recognizing valid scientific courses of action (+8.3%, $p = 0.08$), interpreting graphical representations (8.3%, $p = 0.6$), and understanding basic statistics (+12.5%, $p = 0.7$). Skills five and nine had no net improvement.



Skill	(1) Valid Science	(2) Primary Literature	(3) Uses of Science	(4) Research Design	(5) Make Graphs	(6) Interpret Graphs	(7) Qualitative Skills	(8) Statistics	(9) Justify Predictions	Average
Percent Change	8.3	22.9	8.3	8.3	0	8.3	4.2	12.5	0	8.1

Figure 3: TOSLS breakdown per skill. Analysis of student outcomes in the Fall 2016 cohort. Data was collected from 24 students and analyzed with paired t-test. Significance level is indicated by the presence of asterisks [= p < 0.1, ** = p < 0.05, *** = p < 0.01].*

Classroom-Based Undergraduate Research Experience Survey

On both the pre- and post-CURE Survey, students were asked to react to 22 statements about their perspective on science on a five-point scale from "strongly disagree" (1) to "strongly agree" (5) (Appendix D, Appendix E). The answers from the 15 students that completed both the pre- and post-survey were compared via a paired t-test. No significant change was observed for any of the statements.

The next part of the post-course survey asked students to describe how much experience they had gained from the course in 25 different areas, graded on a five-point scale form “no gain or very little gain” (1) to “very large gain” (5). These questions also gave the option of “not applicable,” which was assigned a value of 0. Data from all 20 students that completed the post-course survey were analyzed (Figure 4). Students reported the highest experiential gains for collecting data (4.5) and the opportunity to have input into the research process (4.4). Similar gains were also seen in students’ experience with analyzing data (4.35), designing a project (4.35), working in small groups (4.25), projects in which no one knows the outcome (4.25), becoming responsible for the project (4.15), and reading primary scientific literature (4.15). Moderate gains were seen in the ability to present posters (3.75) and maintaining lab notebooks (3.75). Predictably, the lowest reported experiential gains were in areas that were not goals of the laboratory, including taking tests in class (1.45), computer modeling (1.45), and reading a textbook (1.65).

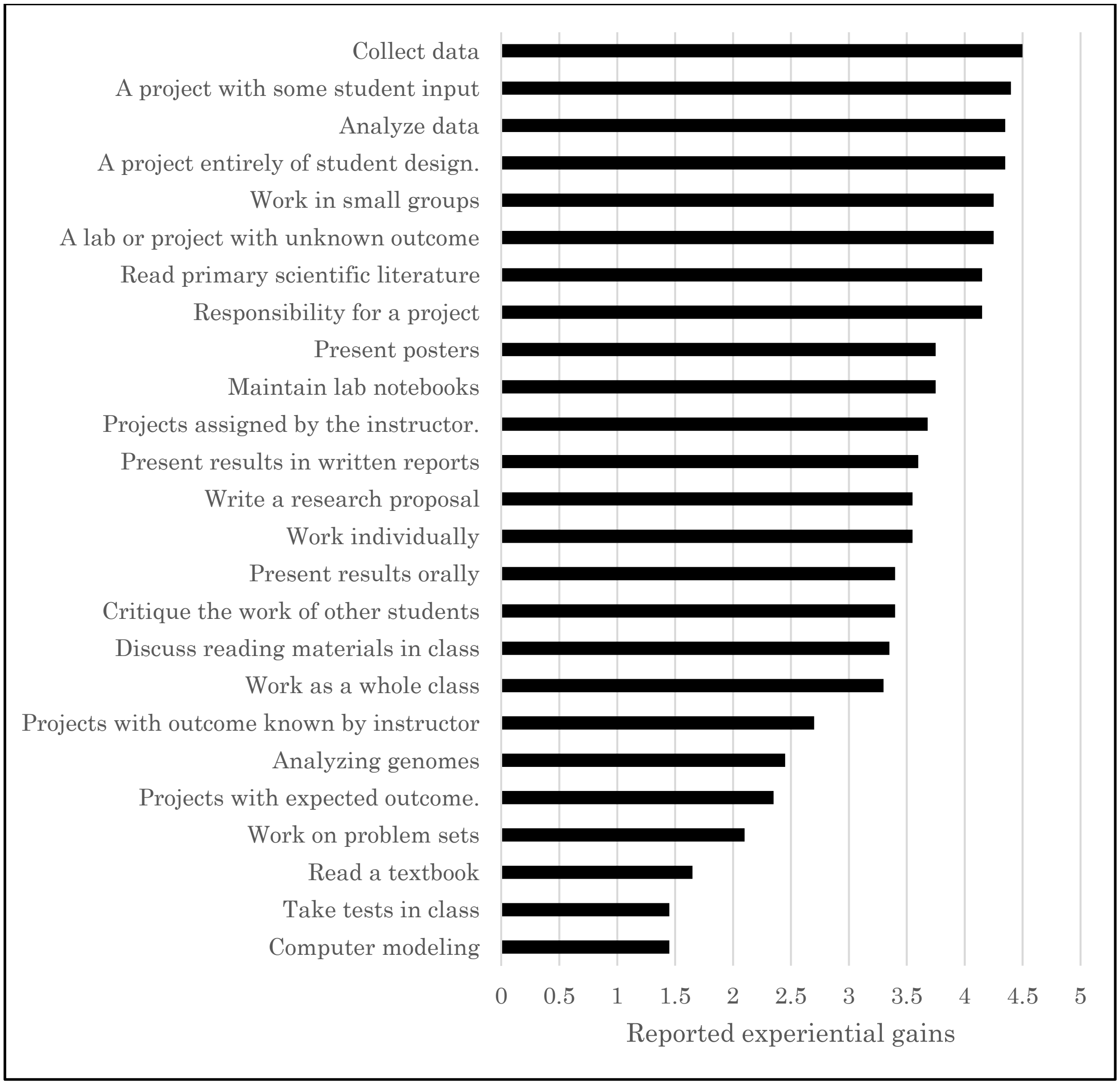


Figure 4: Experiential gains as reported on the CURE survey for twenty CILI-CURE students. Gains were scored by students on a five-point scale from "no gain or very little gain" (1) to "very large gain" (5), with a zero value for items "not applicable".

The final part of the post-course survey asked students to identify the aspects of the laboratory that benefitted them, proposing twenty possible benefits and asking students to score them on a five-point scale from "no gain or very small gain" (1) to "very large gain" (5). Students also had the choice of “not applicable,” which corresponded to a value of zero. The responses of all 20 students that responded to the post-course survey were included in this analysis. The highest-scored benefits were learning laboratory techniques (4.45), the ability to analyze data and other information (4.1), becoming part of the learning community (4.0), and understanding how knowledge is constructed (3.85) (Figure 5). The lowest score was learning about ethical conduct in the field (2.7), which was not directly addressed in the course.

These gains were then compared to gains reported by students in non-research-based laboratories and in other course-based undergraduate research experiences (Lopatto, 2004) (Lopatto et al., 2008). In every category but learning about ethical conduct, CILI-CURE students reported higher learning than that reported by students in non-research-based labs. In most other areas the CILI-CURE scores were between two comparison scores, and in six areas reported higher learning than those reported by Lopatto et al. for other CUREs (2008). These areas included construction of knowledge, analyzing data, understanding science, laboratory techniques, scientific writing, and establishing a learning community.

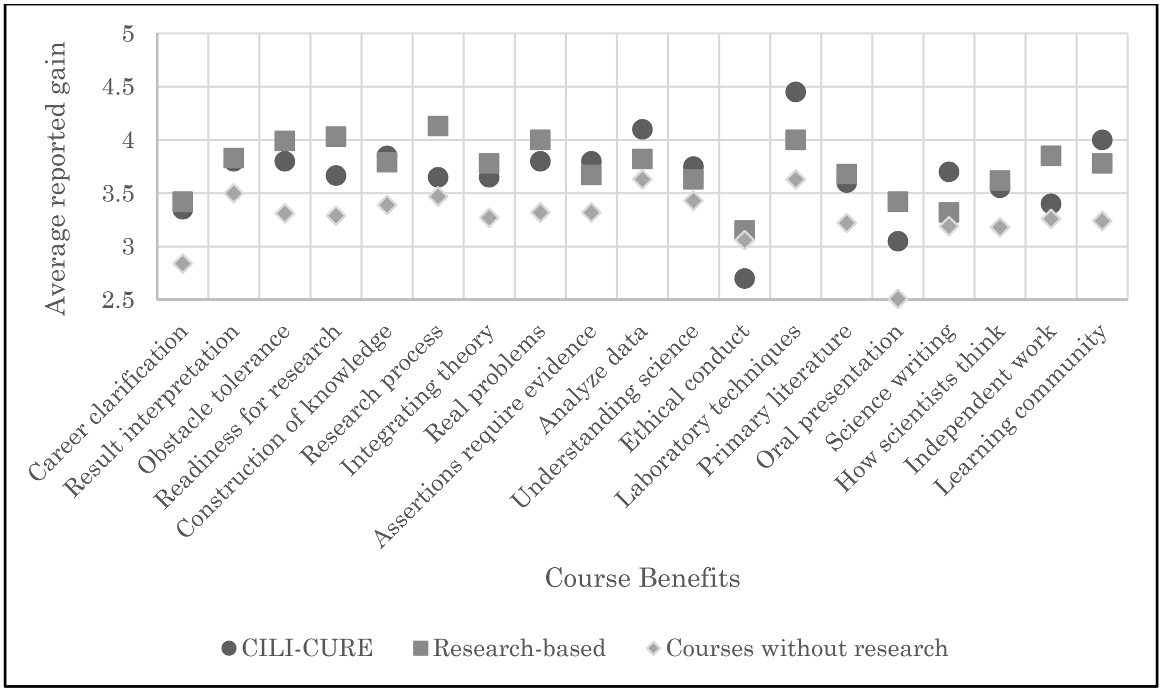


Figure 5: Student-recognized laboratory benefits, based on CURE survey. Scores for other research-based labs were drawn from Lopatto in 2004 and scores for courses without a research component were drawn from Lopatto et al. in 2008.

Baylor Course Evaluation

Due to an issue with the distribution of the Course Evaluation Surveys, only five responses were collected for the 2016 fall cohort. The students that did respond reported that their instructors were obviously interested in the subject material of the lab, and the largest areas of critique was in timeliness of grading and having clear, well-developed expectations for the larger projects.

CHAPTER FOUR

Discussion and Conclusion

Demographics

Despite allowing students to self-select, the CILI-CURE section makeup was largely reflective of all BIO 1105 students in respect to gender, ethnicity, and classification. Due to the small number of students in this study and large white majority, it was not possible to evaluate student outcomes based on ethnicity. This indicates that it might be necessary to intentionally recruit ethnic minorities or open the lab to more sections to evaluate the student outcomes for minorities. In addition, this course had more non-first-year students than the overall population of BIO 1105 students (24% and 13%, respectively), which could indicate that these classes are more attractive to more experienced students.

Test of Scientific Literacy Skills Survey

Significant gains were seen in TOSLS skills one, two, three, six, and eight as well as a significant 8.1% change overall. This indicates that students made significant growth in their understanding of (1) valid scientific arguments, (2) using primary scientific literature, (3) evaluating the appropriate use of scientific information, (6) interpreting graphical representations, and (8) understanding basic statistics. Changes in TOSLS skills were greatest in skill two (understanding and evaluating primary literature, +22.9%) and eight (understanding basic statistics, +12.5%). The improvement in skill two supported the reported student benefit in the CURE Post-Course Survey of strong growth in understanding and evaluating primary literature. This is an essential scientific skill and a major focus in the class, so the improvement in this area indicates that the instruction and practice supported progress. The improvement in understanding basic statistics (TOSLS skill eight) was supported by high gains indicated on CURE topics such as collecting and analyzing data.

The limitations of this assessment method include the possibility of high initial scores on the pre-test, having skills represented by only one question, and the small sample size. The total gain possible on TOSLS questions were limited by the high initial scores on specific questions. In particular, 87.5% and 91.7% of students answered questions six and 10 correctly on the pre-test (respectively). These high initial scores left little room for improvement and so could account for the slight negative change for question six and lack of larger positive change on question 10.

Another limitation of this assessment was the limited number of questions per skill. All TOSLS skills that did not significantly improve were only represented by one question. This may have increased the likelihood that random chance could skew the results and made it more difficult to have statistically significant results.

A final limitation of this style of analysis was the small sample size. Since there were only 29 students in the class and only students over the age of 18 were allowed to complete the survey, some students were not eligible to complete the pre- and/or post-course survey.

Skills that did not significantly improve on the TOSLS included making a graph, using quantitative skills to solve problems, and justifying conclusions based on quantitative data. This may indicate that more explicit instruction on the applications of data analysis could be useful to students, either in the pre-lab quizzes or post-lab worksheets. More time could also be dedicated to the development of these skills in the process of writing the mid-term lab report and the final poster presentation.

Course-Based Undergraduate Research Experience Survey

The CURE survey was helpful to analyze student outcomes in three different categories: student perspective on science, experiential gains, and benefits from the course.

Since there was no significant different in the students' attitudes towards science before and after taking this course, it could be the case that these self-selected students already had a good perspective of science. Analyzing a larger group of students with the CURE Survey or encouraging a higher student response rate could assist in developing a better understanding of how this course affects students' attitudes towards science. In addition, it could be helpful to include topics relevant to these central ideas in the post-lab worksheets to allow for more open discussion and development of ideas.

Some lower reported experiential gains included presenting results in written reports (3.6), presenting posters (3.75), and maintaining lab notebooks (3.75). Reminding students of these long-term goals regularly in lab meetings could be helpful in showing the connections between the daily work in the lab and the large products. In addition, scheduling more in-lab time to develop these skills further and have peer critiques could assist in giving a more complete experience in these areas. These relatively lower scores could also reflect students' realistic perspective on their abilities in these areas. These skills are learned over periods of years rather than a few months, and it is promising that students realize that they still have a lot to learn.

CILI-CURE students reported benefits from the course generally equivalent to those laid out by Lopatto in 2004 and almost exclusively greater than those without a research component (Lopatto et al., 2008). This result supports the concept that this inquiry-based lab meets the objective of teaching the nature of science and process-of-science skills. The greatest reported gain for CILI-CURE students was in learning lab techniques, which surpassed the outcomes for both non-research-based and research-based laboratory courses. This can be interpreted to mean that students see the value of learning to use equipment such as light microscopes and micropipettors and feel confident in their ability to use these tools.

The one area of smaller reported gain was in understanding the ethical conduct of the field. Although this is not a stated goal of the program, it is worth considering whether some discussion of this could help students better understand the field of biology. In addition, adding some discussion of ethical biological practices could influence students' responses on the previously-discussed perception of science questions. These discussions could be included in process of reporting experimental outcomes in the lab report and scientific poster presentation, and a larger discussion could be included in the periodic discussions on the applications of scientific discovery and societal issues.

Conclusion

As discussed previously, one of the biggest obstacles in creating a highly-involved, research-based laboratory curriculum is simply the time, effort, and organization it requires to function smoothly, especially on a large scale. As the CILI-CURE curriculum continues to be refined, it will be essential to establish clear means of communication and thoughtful, instructive means of assessing student outcomes. As the course evaluation survey outcomes suggest, assessments that require more of the student also require more of the grader for the assessments to be meaningful. Creating a clear set of expectations, deadlines, and a system for timely feedback will be essential to ensure that students are getting the most benefit possible from the course. The limited response rate of the Course Evaluation Survey indicates that at times the students felt overwhelmed by the amount of material and assignments. Future course revisions should evaluate the delivery of material in accordance with the level of the class.

Inquiry-based learning has become the flagship of modern education, and its benefits are demonstrated in this study. Gains in assessing scientific sources, understanding basic statistics, gauging the validity of scientific arguments, assuming responsibility for experiments, and data collection and analysis indicate that the CILI-CURE curriculum supported student learning of critical scientific skills. TOSLS and CURE Survey data demonstrated that students made gains in both scientific literacy and confidence following the CILI-CURE experience. Future research on this course should examine subsequent semesters to verify the consistency of the gains demonstrated in this study and compare the outcomes of the CILI-CURE students to their peers in non-research-based laboratory courses. In addition, it would be interesting to include CILI-CURE students in a longitudinal study to examine if this early course-based research experience has any long-term effects on their perceptions of science or their continuance in science-related fields.

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APPENDICES

APPENDIX A

Comparison of a Traditional and CILI-CURE Curriculum

Week	Traditional Curriculum	CILI-CURE
1	Metric System & Light Microscopes • Converting between measurements in metric system • Using compound & dissecting microscopes	BioBlitz • Teamwork • Biodiversity
2	Diffusion & Osmosis • Concentration • Diffusion and osmosis	Ciliate Challenge • Dissecting microscopes • Constructivist learning • Characteristics of ciliates • Lab notebooks
3	Bacteria • Introduction to prokaryotes • Gram staining	Primary Literature • Growth mindset • Primary scientific articles • Experimental design
4	Human Physiology • Blood pressure • Vision	Experimental Design • Creativity of science • Understanding deeply • Micropipetting • Compound microscopy
5	Exam 1	Beginning the Experiment • Counting chambers • Serial dilutions • Deductive/inductive reasoning
6	Enzymes • Sensitivity of enzymes to environmental conditions • Spectrophotometer	Evaluating the Experiment • Scientific articles (organization, types, evaluation, databases) • Excel analysis tools
7	Cellular Respiration • Anaerobic fermentation • Aerobic respiration	Results and Analysis • Data analysis and presentation • Null hypotheses • Statistical test

8	Photosynthesis • Paper chromatography • Spectrophotometer • pH indicator	Peer Review + Soil Ciliates • Importance of peer review process • Soil collection • Non-flooded plates
9	Exam 2	Soil & Ciliates • Ciliate taxonomy • Soil assessment and metadata • Ecosystems
10	Vertebrate Animal Tissues • Observation of epithelial, connective, muscle, and nervous tissue slides	Characterizing Ciliates • Dichotomous keys • Morphological characteristics • Picking & culturing
11	Rat Dissection • Dissection skills • External features of rat • Skeletal system of rat	Picking Protists • Ciliate classification • Origin of ciliates • Evolution theory
12	Rat Dissection • Muscular system of rat • Internal organs of rat	DNA Extraction • Scientific posters • DNA extraction • Ciliate diversity
13	*No Lab Meeting*	Polymerase Chain Reaction • PCR • Scientific posters • Barcoding/metabarcoding
14	Rat Dissection • Urogenital system of rat • Circulatory system of rat	Gel Electrophoresis • Gel electrophoresis • Interdisciplinary nature of science
15	Exam 3	Symposium • Poster presentations • Peer evaluation

APPENDIX B

Test of Scientific Literacy Skills (TOSLS) Survey

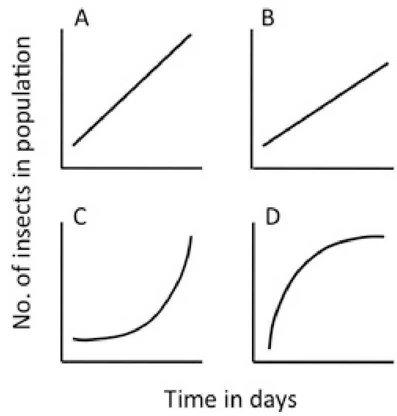
Welcome to BIO 1105 and the Test of Scientific Literacy Skills (TOSLS). This quiz is a part of how evaluating the effectiveness of the new BIO 1105 lab curriculum by assessing learning gains on the nature of science and scientific literature. You must be at least 18 years old to participate. If you are 18 years or older, taking BIO 1105 (or an equivalent course), and willing to complete this survey, please complete the following series of questions to the best of your ability. You will receive a set number of points for completing the quiz, regardless of how many questions you get correct. Your answers will be reported anonymously and only aggregate data (no individual data) will be reported. Please be advised that you are not compelled to participate. You may elect not to complete this quiz, and you will have plenty of opportunities throughout the semester to obtain points in the lab. If you change your mind about completing the quiz, please leave the site and leave the quiz incomplete. It will be assumed that the submission of a completed quiz is your consent for participation. If you have any questions about this quiz, you may contact Josie Minick at Josie_Minick@baylor.edu. This quiz is adapted from the TOSLS established by Cara Gormally, Peggy Brickman, and Mary Lutz at the Georgia Institute of Technology and the University of Georgia.

1. Which of the following is a valid scientific argument?
    a. Measurements of sea level on the Gulf Coast taken this year are lower than normal; the average monthly measurements were almost 0.1 cm lower than normal in some areas. These facts prove that sea level rise is not a problem.
    b. A strain of mice was genetically engineered to lack a certain gene, and the mice were unable to reproduce. Introduction of the gene back into the mutant mice restored their ability to reproduce. These facts indicate that the gene is essential for mouse reproduction.
    c. A poll revealed that 34% of Americans believe that dinosaurs and early humans co-existed because fossil footprints of each species were found in the same location. This widespread belief is appropriate evidence to support the claim that humans did not evolve from ape ancestors

d. This winter, the northeastern US received record amounts of snowfall, and the average monthly temperatures were more than 2°F lower than normal in some areas. These facts indicate that climate change is occurring.

2. While growing vegetables in your backyard, you noticed a particular kind of insect eating your plants. You took a rough count (see data below) of the insect population over time. Which graph shows the best representation of your data?

Time (days)	Insect Population (number)
2	7
4	16
8	60
10	123



3. A study about life expectancy was conducted using a random sample of 1,000 participants from the United States. In this sample, the average life expectancy was 80.1 years for females and 74.9 years for males. What is one way that you can **increase your certainty** that women truly live longer than men in the United States' general population?
   a. Subtract the average male life expectancy from the average female expectancy. If the value is positive, females live longer.
   b. Conduct a statistical analysis to determine if females live significantly longer than males.
   c. Graph the mean (average) life expectancy values of females and males and visually analyze the data.
   d. There is no way to increase your certainty that there is a difference between sexes

4. Which of the following research studies is **least likely** to contain a confounding factor (variable that provides an alternative explanation for results) in its design?
   a. Researchers randomly assign participants to experimental and control groups. Females make up 35% of the experimental group and 75% of the control group.

b. To explore trends in the spiritual/religious beliefs of students attending U.S. universities, researchers survey a random selection of 500 freshmen at a small private university in the South.
c. To evaluate the effect of a new diet program, researchers compare weight loss between participants randomly assigned to treatment (diet) and control (no diet) groups, while controlling for average daily exercise and pre-diet weight.
d. Researchers tested the effectiveness of a new tree fertilizer on 10,000 saplings. Saplings in the control group (no fertilizer) were tested in the fall, whereas the treatment group (fertilizer) were tested the following spring.

Background for question 5: The following graph appeared in a scientific article[1] about the effects of pesticides on tadpoles in their natural environment.

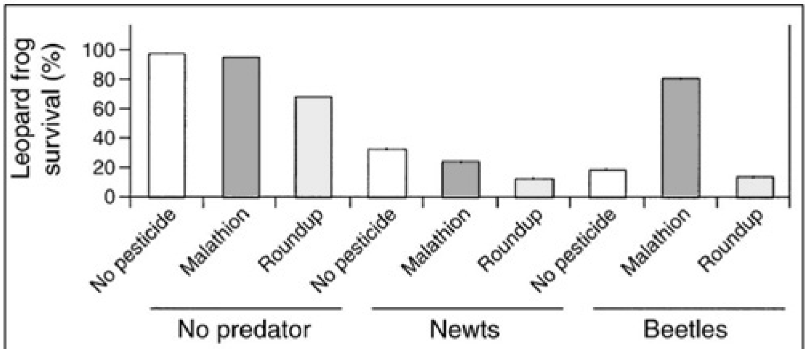


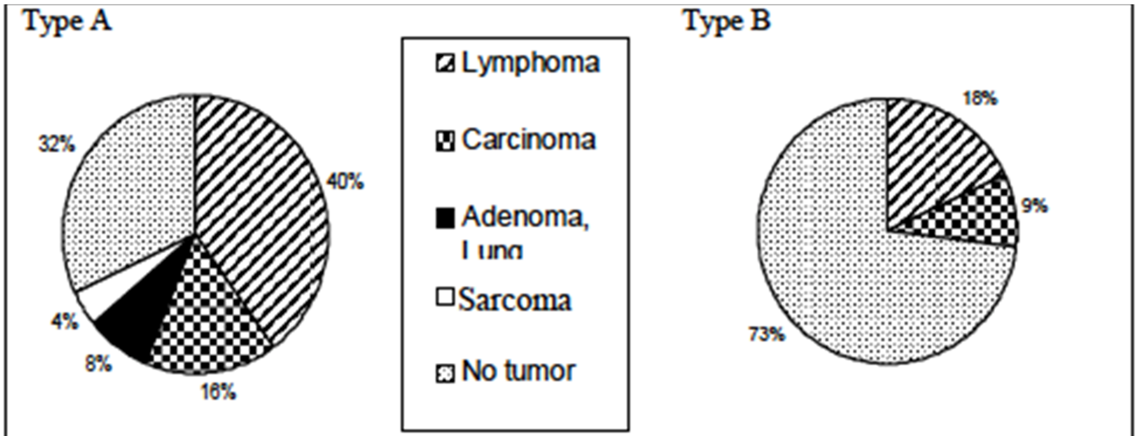
Fig. 2. Total survival of Leopard frog tadpoles living in ponds with 2 pesticides added (Malathion and Roundup) and 2 tadpole predators present (newts and beetles).

[1] Modified from Relyea, R.A., N.M. Schoeppner, J.T. Hoverman. 2005. Pesticides and amphibians: the importance of community context. Ecological Applications 15: 1125-1134

5. When beetles were introduced as predators to the Leopard frog tadpoles, and the pesticide Malathion was added, the results were unusual. Which of the following is a plausible hypothesis to explain these results?

a. The Malathion killed the tadpoles, causing the beetles to be hungrier and eat more tadpoles.
b. The Malathion killed the tadpoles, so the beetles had more food and their population increased.
c. The Malathion killed the beetles, causing fewer tadpoles to be eaten.
d. The Malathion killed the beetles, causing the tadpole population to prey on each other.

6. Which of the following is the **best** interpretation of the graph below[2]?



Tumors found in type A and type B mice. Pie chart depicts relative incidence of tumors. Numbers outside each slice denote the percentage of specific tumor type.

Modified from Wang, Y., S. Klumpp, H.M. Amin, H. Liang, J. Li, Z. Estrov, P. Zweidler-McKay, S.J.Brandt, A. Agulnick, L.
Nagarajan. 2010. SSBP2 is an in vivo tumor suppressor and regulator of LDB1 stability. Oncogene 29: 3044-3053.

a. Type "A" mice with Lymphoma were more common than type "A" mice with no tumors.
b. Type "B" mice were more likely to have tumors than type "A" mice.
c. Lymphoma was equally common among type "A" and type "B" mice.
d. Carcinoma was less common than Lymphoma only in type "B" mice.

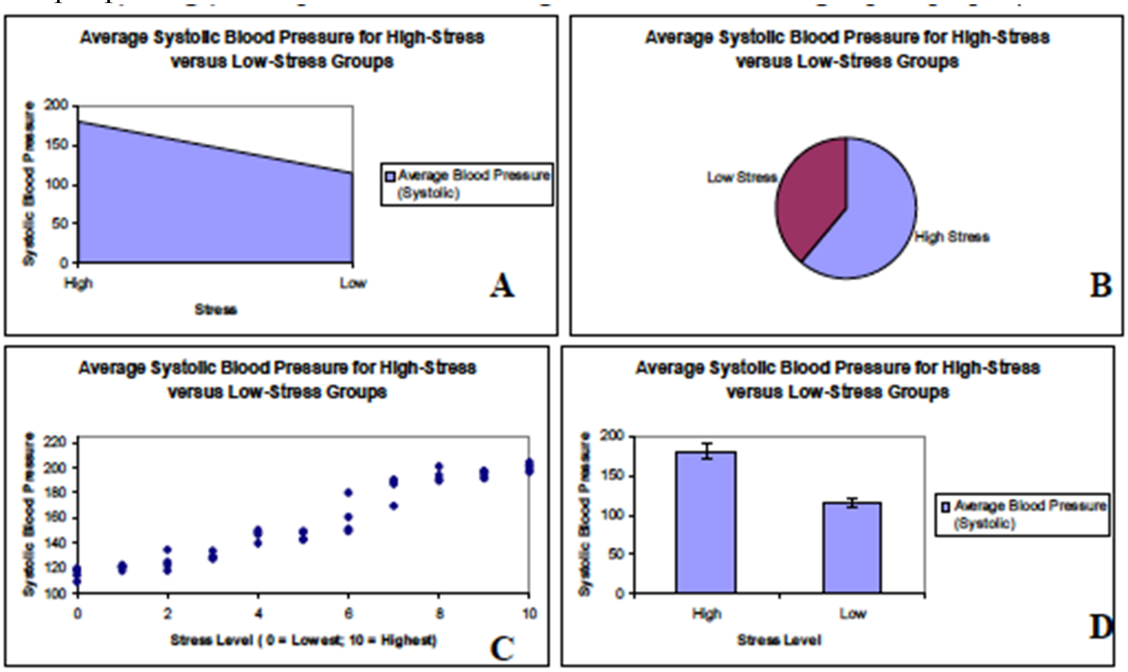
Background for question 7: Use the excerpt below (modified from a recent news report on MSNBC.com) for the next few questions.

"A recent study, following more than 2,500 New Yorkers for 9+ years, found that people who drank diet soda every day had a 61% higher risk of vascular events, including stroke and heart attack, compared to those who avoided diet drinks. For this study, Hannah Gardner's research team randomly surveyed 2,564 New Yorkers about their eating behaviors, exercise habits, as well as cigarette and alcohol consumption. Participants were also given physical check-ups, including blood pressure measurements and blood tests for cholesterol and other factors that might affect the risk for heart attack and stroke. The increased likelihood of vascular events remained even after Gardener and her colleagues accounted for risk

factors, such as smoking, high blood pressure and high cholesterol levels. The researchers found no increased risk among people who drank regular soda."

7. The excerpt above comes from what type of source of information?
   a. Primary (Research studies performed, written and then submitted for peer-review to a scientific journal.)
   b. Secondary (Reviews of several research studies written up as a summary article with references that are submitted to a scientific journal.)
   c. Tertiary (Media reports, encyclopedia entries or documents published by government agencies.)
   d. None of the above

8. Researchers found that chronically stressed individuals have significantly higher blood pressure compared to individuals with little stress. Which graph would be most appropriate for displaying the mean (average) blood pressure scores for high-stress and low-stress groups of people?



9. The <u>**most important**</u> factor influencing you to categorize a research article as trustworthy science is:
   a. the presence of data or graphs
   b. the article was evaluated by unbiased third-party experts
   c. the reputation of the researchers
   d. the publisher of the article

10. A gene test shows promising results in providing early detection for colon cancer. However, 5% of all test results are falsely positive; that is, results indicate that cancer is present when the patient is, in fact, cancer-free. Given this false positive rate, how many people out of 10,000 would have a false positive result and be alarmed unnecessarily?
   a. 5
   b. 35
   c. 50
   d. 500

11. Why do researchers use statistics to draw conclusions about their data?
   a. Researchers usually collect data (information) about everyone/everything in the population.
   b. The public is easily persuaded by numbers and statistics.
   c. The true answers to researchers' questions can only be revealed through statistical analyses.
   d. Researchers are making inferences about a population using estimates from a smaller sample.

12. Which of the following actions is a valid scientific course of action?
   a. A scientific journal rejects a study because the results provide evidence against a widely-accepted model.
   b. The scientific journal, Science, retracts a published article after discovering that the researcher misrepresented the data.
   c. A researcher distributes free samples of a new drug that she is developing to patients in need.
   d. A senior scientist encourages his graduate student to publish a study containing ground-breaking findings that cannot be verified.

Background for question 13: Researchers interested in the relation between River Shrimp (Macrobrachium) abundance and pool site elevation, presented the data in the graph below. Interestingly, the researchers also noted that water pools tended to be shallower at higher elevations.

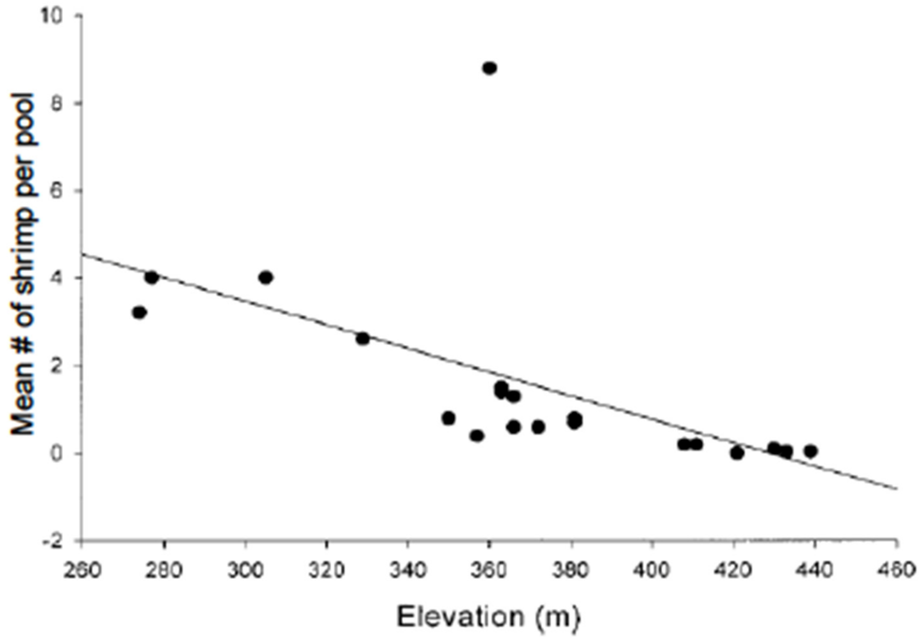


FIG. 3. Relationship between total abundance of *Macrobrachium* (1988–2002) and elevation in Quebrada Prieta.

12. Which of the following is a plausible hypothesis to explain the results presented in the graph?

    a. There are more water pools at elevations above 340 meters because it rains more frequently in higher elevations.
    b. River shrimp are more abundant in lower elevations because pools at these sites tend to be deeper.
    c. This graph cannot be interpreted due to an outlying data point.
    d. As elevation increases, shrimp abundance increases because they have fewer predators at higher elevations

APPENDIX C

Test of Scientific Literacy Skills (TOSLS) Skills

Skill	Description	Question	Answer
1	Identify a valid scientific argument (e.g., recognizing when scientific evidence supports a hypothesis)	1	B
2	Conduct an effective literature search (e.g. Evaluate the validity of sources (e.g., websites, peer reviewed journals) and distinguish between types of sources)	7	C
		9	B
3	Evaluate the use and misuse of scientific information (e.g. Recognize a valid scientific course of action, distinguish the appropriate use of science to make societal decisions)	12	B
4	Understand elements of research design and how they impact scientific findings/conclusions (e.g. identify strengths and weaknesses in research related to bias, sample size, randomization, experimental control)	4	C
5	Make a graph	8	D
6	Read and interpret graphical representations of data	2	C
		5	C
		6	A
7	Solve problems using quantitative skills, including probability and statistics (e.g. calculate means, probabilities, percentages, frequencies)	10	D
8	Understand and interpret basic statistics (e.g. interpret error bars, understand the need for statistics	3	B
		11	D
9	Justify inferences, predictions, and conclusions based on quantitative data	13	B

APPENDIX D

Course-Based Undergraduate Research Experience (CURE) Pre-Course Survey

Welcome to BIO 1105 and the CURE pre-course survey. This collaborative project involves faculty and students from many colleges and universities. Together we are determining how our science laboratory courses can better facilitate science learning and more actively engage and retain science students. To accomplish this task we have developed a pre-course and post-course survey to assess learning gains of this introductory lab science course. You must be at least 18 years old to participate. If you are 18 years old or older, beginning the introductory biology course, and the instructor has asked you to participate in this survey, please fill out the pre-course survey questions below. Identifying information is only for correlating pre and post responses and student outcomes. For the purpose of tracking pre and post response rates from multiple courses, we have asked you to identify yourself using your name, BU ID#, course, course number and instructor's name. Through alignment of your pre-course and post-course responses, we will be able to measure change. Long term outcomes (graduation and retention in the major, for example) may also be collected from Baylor University databases. Your individual responses will not be revealed to your course instructor, and your answers will not affect your grade in the course. All participants will be given a grade equivalent to a lab quiz for participating. We will not know whether you answered the questions or opted out. The lead analysts for the project will keep your data confidential and only aggregate data (no individual data) will be reported. Please be advised that you are not compelled to participate. You may elect to leave individual questions blank. In addition, a "not applicable" option is available if the question does not pertain to you. If you change your mind about completing the survey, please leave the site and leave the survey incomplete. It will be assumed that the submission of a completed survey is your consent for participation. If you have any questions about this survey, you may contact Dr. Tamarah Adair at Tamarah_Adair@baylor.edu. This survey is adapted from the CURE survey developed by Prof. Lopatto at Grinnell College (copyright at Grinnell College). Funding was provided to him by the Howard Hughes Medical Institute, and this survey has been previously approved by institutional review boards.

What is your age?

- o under 18
- o over 18

Gender

- Male
- Female
- Prefer not to answer

To which racial or ethnic group(s) do you most identify?

Alaskan Native
American Indian
Asian American
Black or African American
Filipino
Foreign national
Hawaiian
Hispanic/Latino
Pacific Islander
White
Other
Prefer not to answer

What is your current status?

- I am a first-year college undergraduate
- I am a second-year college undergraduate
- I am a third-year college undergraduate
- I am a fourth-year college undergraduate
- Other

Which of the following best describes you?

- I am a first generation college student (the first person other than a sibling in my family to attend college)
- I am a transfer student from another 4-year university
- I attended a community or a junior college prior to Baylor
- I am in the ROTC program
- I am an armed forces veteran
- I am currently serving in the armed forces (not including ROTC)
- I was homeschooled prior to Baylor

What score did you earn on the AP BIO test?

- 1
- 2
- 3
- 4
- 5
- Did not take it
- Prefer not to answer

What is your major?

Pre-Biology/Biology
Chemistry/Biochemistry
Health Science Studies
Psychology/Neuroscience
Medical Humanities
Undecided
Other ___________________
Prefer not to answer

This question is about your goals beyond your undergraduate degree. It is difficult to list all the goals people may have. The purpose of this question is to learn how many students plan to go on in science, medicine, or other fields, as well as to learn how many students do not plan to go to post-graduate education in their near future. Please choose one:

- My goal is to go to graduate school for a Ph.D. degree in a biology-related field.
- My goal is to go to graduate school for a Ph.D. degree in the physical sciences (including engineering, math, chemistry and computer science)
- My goal is to go to graduate school for a Masters Degree in a biology-related field.
- My goal is to go to graduate school for a Masters Degree in the physical sciences (including engineering, math, chemistry and computer science).
- My goal is to go to graduate school for a Masters or a Ph.D. degree in a social science (including psychology, sociology, anthropology, economics, and political science).
- My goal is to go to graduate school for a Masters or a Ph.D. in humanities or fine arts.
- My goal is to earn a certification or degree that will qualify me for teaching.
- My goal is to go to school for a medical degree (M.D.).
- My goal is to go to school for an M.D./Ph.D.
- My goal is to go to school for other health professions (including veterinary, dental, physician assistant)
- My goal is to go to a type of graduate education not mentioned above, such as law school.
- My goal does not include graduate education for at least the near future.
- Not applicable/Prefer not to answer

Here is a list of common reasons for taking a course. Please read each one and indicate if the reason was important to your decision to take this course.

For each reason, please select "not important", "moderately important", "very important", or "not applicable"

- To fill a lab science requirement for my science major
- To fill a lab science requirement for my non-science requirement
- I need it for graduate or professional school
- I need it for my desired employment after college
- Interest in the subject matter
- To learn lab techniques
- To learn about science and the research process
- To get hands-on research experience
- It fit in my schedule
- The course and/or instructor has a good reputation

Please look over these elements that might be included in the laboratory course. For each element, give an estimate of your current level of ability before the course begins. Your current level of ability may be a result of previous courses, or it may be a result of other experiences such as jobs or special programs (internships etc.).

Please select "no experience or feel inexperienced", "little experience", "some experience", "much experience", "extensive experience or mastered this element", or "not applicable/prefer not to answer"

- A scripted lab or project in which the students know the expected outcome
- A lab or project in which only the instructor knows the outcome.
- A lab or project where no one knows the outcome
- At least one project that is assigned and structured by the instructor
- A project in which students have some input into the research process and/or what is being studied
- A project entirely of student design
- Work individually
- Work as a whole class
- Work in small groups
- Become responsible for a part of the project
- Read primary scientific literature
- Write a research proposal
- Collect data
- Analyze data
- Present results orally
- Present results in written papers or reports
- Present posters

- Critique the work of other students
- Listen to lectures
- Read a textbook
- Work on problem sets
- Take tests in class
- Discuss reading materials in class
- Maintain lab notebook
- Computer modeling
- Analyze genomes

Your opinions about yourself and about science. It has become common to say that no student is an empty bucket, waiting for a teacher to pour in knowledge. Research on learning acknowledges that students approach a course with well-formed opinions of themselves and of the subject matter. In this section we present questions about science and questions about you. These will help us put learning in context.

For each item below please rate your agreement with the item, selecting "strongly disagree", "disagree", "neutral", "agree", "strongly agree", or "not applicable".

- Even if I forget the facts, I'll still be able to use the thinking skills I learn in science
- You can rely on scientific results to be true and correct
- The process of writing in science is helpful for understanding scientific ideas
- When scientific results conflict with my personal experience, I follow my experience in making choices
- Students who do not major/concentrate in science should not have to take science courses
- I wish science instructors would just tell us what we need to know so we can learn it
- Creativity does not play a role in science
- Science is not connected to non-science fields such as history, literature, economics, or art
- When experts disagree on a science question, it's because they don't know all the facts yet
- I get personal satisfaction when I solve a scientific problem by figuring it out myself
- Since nothing in science is known for certain, all theories are equally valid
- Science is essentially an accumulation of facts, rules, and formulas
- I can do well in science courses
- Real scientists don't follow the scientific method in a straight line
- There is too much emphasis in science classes on figuring things out for yourself

- Only scientific experts are qualified to make judgments on scientific issues
- Scientists know what the results of their experiments will be before they start
- Explaining scientific ideas to others has helped me understand the ideas better
- The main job of the instructor is to structure the work so that we can learn it ourselves
- Scientists play with statistics to support their own ideas
- Lab experiments are used to confirm information studied in science class
- If an experiment shows that something doesn't work, the experiment was a failure

Below are ten pairs of statements. The 1-6 number scale between them is used to indicate how well a statement or a pair of statements describes you. For example, on the first pair, a "6" would indicate you are very action oriented, while a "1" would reflect that you are very reflective, and a "4" would indicate you were more action- oriented than reflective, but somewhat reflective. For each pair of statements, choose a number that indicates how well the statement describes you. Do not worry that some pairs are not opposite.

- I would describe myself as reflective : I would describe myself as action-oriented
- I prefer subjects with precise answers : I prefer subjects with multiple interpretations
- I value patience : I value getting things done
- I like things to be varied and colorful : I like to be exact and precise
- I would describe myself as a doer : I would describe myself as an observer
- I take a precise and calculated approach to solving problems : I take a creative and imaginative approach to solving problems
- I would describe myself as evaluative and logical : I would describe myself as receptive and accepting
- I like to watch what is going on : I like to see the results of my actions
- I strive for versatility : I strive for accuracy
- I am reserved : I am quick to respond

APPENDIX E

Course-Based Undergraduate Research Experience (CURE) Post-Course Survey

Welcome to the CURE post course survey.
This collaborative project involves faculty and students from many colleges and universities. Together we are determining how our science laboratory courses can better facilitate science learning and more actively engage and retain science students. To accomplish this task we have developed a pre-course and post-course survey to assess learning gains of this introductory lab science course. You must be at least 18 years old to participate. If you are 18 years old or older, beginning the introductory biology course, and the instructor has asked you to participate in this survey, please fill out the post-course survey questions below. Identifying information is only for correlating pre and post responses and student outcomes. For the purpose of tracking pre and post response rates from multiple courses, we have used your email. Through alignment of your pre-course and post-course responses, we will be able to measure change. Long term outcomes (graduation and retention in the major, for example) may also be collected from Baylor University databases. Your individual responses will not be revealed to your course instructor, and your answers will not affect your grade in the course. All participants will be given a grade equivalent to a lab quiz for participating. We will not know whether you answered the questions or opted out. The lead analysts for the project will keep your data confidential and only aggregate data (no individual data) will be reported. Please be advised that you are not compelled to participate. You may elect to leave individual questions blank. In addition, a "not applicable" option is available if the question does not pertain to you. If you change your mind about completing the survey, please leave the site and leave the survey incomplete. It will be assumed that the submission of a completed survey is your consent for participation. This will automatically be recorded through your email. You do not need to contact your professor. If you have any questions about this survey, you may contact Dr. Tamarah Adair at Tamarah_Adair@baylor.edu. This survey is adapted from the CURE survey developed by Prof. Lopatto at Grinnell College (copyright at Grinnell College). Funding was provided to him by the Howard Hughes Medical Institute, and this survey has been previously approved by institutional review boards.

Are you at least 18 years old?

- o Yes
- o No

What is your major?

Pre-Biology/Biology
Chemistry/Biochemistry
Health Science Studies
Psychology/Neuroscience
Medical Humanities
Undecided
Other ___________________
Prefer not to answer

The next question is about how the experience of this course influenced your plans about post-graduate education. After taking this course,

- o I have not considered any post-graduate education
- o I now plan not to pursue post-graduate education
- o I now plan to pursue a Master's degree in a science-related field
- o I now plan to pursue a Doctoral degree in a science-related field
- o I now plan to pursue a Master's degree in a field other than science
- o I now plan to pursue a Doctoral degree in a field other than science
- o I now plan to pursue a medical degree
- o I now plan to pursue a law, architectural, or other degree
- o Not applicable/ prefer not to answer

Please rate how much learning you gained from each element you experienced in this course. Please choose from "no gain or very small gain", "small gain", "moderate gain", "large gain", "very large gain", "not applicable/prefer not to answer".

- A scripted lab or project in which the students know the expected outcome
- A lab or project in which only the instructor knows the outcome.
- A lab or project where no one knows the outcome
- At least one project that is assigned and structured by the instructor
- A project in which students have some input into the research process and/or what is being studied
- A project entirely of student design
- Work individually
- Work as a whole class
- Work in small groups
- Become responsible for a part of the project
- Read primary scientific literature
- Write a research proposal

- Collect data
- Analyze data
- Present results orally
- Present results in written papers or reports
- Present posters
- Critique the work of other students
- Listen to lectures
- Read a textbook
- Work on problem sets
- Take tests in class
- Discuss reading materials in class
- Maintain lab notebook
- Computer modeling
- Analyze genomes

In this section of the survey you will be asked to consider a variety of possible benefits you may have gained from your laboratory experience. If for any reason you prefer not to answer, or consider the question irrelevant to you, please choose the "Not applicable / Prefer not to answer" option. Please choose “no gain or very small gain”, “small gain”, “moderate gain”, “large gain”, “very large gain”, or “not applicable/prefer not to answer”.

- Clarification of a career path
- Skill in the interpretation of results
- Tolerance for obstacles faced in the research process
- Readiness for more demanding research
- Understanding how knowledge is constructed
- Understanding of the research process in your field
- Ability to integrate theory and practice
- Understanding of how scientists work on real problems
- Understanding that scientific assertions require supporting evidence
- Ability to analyze data and other information
- Understanding science
- Learning ethical conduct in your field
- Learning laboratory techniques
- Ability to read and understand primary literature
- Skill in how to give an effective oral presentation
- Skill in science writing
- Self-confidence
- Understanding of how scientists think
- Learning to work independently
- Becoming part of the learning community
- Confidence in my potential to be a teacher of science

For each item below please rate your own agreement with the item. Please choose “strongly disagree”, “disagree”, “neutral”, “agree”, “strongly agree”, or “not applicable/prefer not to answer”.

- This course was a good way of learning about the subject matter
- This course was a good way of learning about the process of scientific research
- This course had a positive effect on my interest in science
- I was able to ask questions in this class and get helpful responses

In the pretest, you responded to questions about science. Below the questions are posed again. Your answers will help us decide between two hypotheses, that the opinions are reliable over time (test-retest reliability) or that the opinions change as a result of your experience. For each item below, please rate your agreement with the item by indicating “strongly disagree”, “disagree”, “neutral”, “agree”, “strongly agree”, “not applicable/prefer not to answer”.

- Even if I forget the facts, I’ll still be able to use the thinking skills I learn in science
- You can rely on scientific results to be true and correct
- The process of writing in science is helpful for understanding scientific ideas
- When scientific results conflict with my personal experience, I follow my experience in making choices
- Students who do not major/concentrate in science should not have to take science courses
- I wish science instructors would just tell us what we need to know so we can learn it
- Creativity does not play a role in science
- Science is not connected to non-science fields such as history, literature, economics, or art
- When experts disagree on a science question, it’s because they don’t know all the facts yet
- I get personal satisfaction when I solve a scientific problem by figuring it out myself
- Since nothing in science is known for certain, all theories are equally valid
- Science is essentially an accumulation of facts, rules, and formulas
- I can do well in science courses
- Real scientists don’t follow the scientific method in a straight line
- There is too much emphasis in science classes on figuring things out for yourself
- Only scientific experts are qualified to make judgments on scientific issues
- Scientists know what the results of their experiments will be before

they start

- Explaining scientific ideas to others has helped me understand the ideas better
- The main job of the instructor is to structure the work so that we can learn it ourselves
- Scientists play with statistics to support their own ideas
- Lab experiments are used to confirm information studied in science class
- If an experiment shows that something doesn't work, the experiment was a failure

APPENDIX F

Baylor Course Evaluation

1. Select the answer which best completes the following sentence: "This course is…"
    a. "In my major field of study."
    b. "a university requirement for my degree program, but not in my major field of study."
    c. "an elective (whether or not in my major field of study."

2. Did your academic background prepare you for this class?
    a. Yes
    b. No

3. What was your classification at the beginning of this semester?
    a. Freshman
    b. Sophomore
    c. Junior
    d. Senior

4. You spent approximately how many hours per week in preparation for this lab?
    a. Less than 3
    b. 3-5
    c. 6-8
    d. 9-11
    e. 12 or more

5. Grade you expect to receive in this course:
    a. A
    b. B
    c. C
    d. D
    e. F
    f. I (incomplete)

6. What percentage of laboratory sessions did you attend?
    a. 0-20%
    b. 21-40%
    c. 41-60%

d. 61-80%
e. 81-100%

Questions 7-19: Please indicate your agreement with the statements below by indicating “strongly agree”, “agree”, “slightly agree”, “slightly disagree”, “disagree”, “strongly disagree”

7. My lab instructors were well prepared and organized in lab.

8. When there were hazards involved with a lab activity, my lab instructor would caution the class on how to perform the activity safely.

9. I would rate my lab instructor’s effectiveness as excellent.

10. The lab instructor appeared interested in the subject matter

11. I understood what was expected in lab assignments and how they would be graded

12. My lab instructor provided an effective means to communicate with them outside of lab time.

13. The lab instructor treated students with respect

14. The lab instructor’s spoken communication was clear and understandable.

15. The lab instructor had adequate background knowledge to provide appropriate answers to questions that arose in lab.

16. The grading that was the direct responsibility of the lab instructor was reported in a timely manner.

17. The lab instructor maintained an environment that was conducive to learning

18. The laboratory requirements that were a direct responsibility of the lab instructor was presented in a clear and understandable fashion

19. If given a choice, I would choose these individuals to be my lab instructor in a future laboratory course.

20. Did the lab instructors exert pressure on you to complete the laboratory activities early, in less than the full laboratory period?
    a. Yes
    b. No

21. What should the lab instructors focus on in order to improve?

22. Any other specific comments?

23. This laboratory was structured to allow students to experience open inquiry, including all the ups and downs of scientific research. After taking this lab, how would you describe the process of science?