HOW DOES TAKING A FOUNDATIONAL COURSE IN BIOLOGY IMPROVE TEACHING EFFECTIVENESS?

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By

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Abstract

This thesis project centers on the development and assessment of two biology courses at California State University East Bay (Foundational Biology, BIOL-3011 and BIOL-3012) designed as upper level courses in biology specifically designed for pre-service and in-service primary school teachers with a Multiple Subject credential working towards a Foundational Level General Science credential. The teachers involved in the courses showed no significant gains in student achievement when measured using a concept inventory; however, they showed higher passage rates than the state average on subject matter competency exams. Their underlying attitudes of perceiving biology as being a difficult subject may be a barrier to them mastering the content, but the ability to experience and practice effective science pedagogy increased their confidence and excitement to bring hands-on biology lessons to their students.

The second component of this project is the creation of a biology concept inventory that may be used to measure biological misconceptions for a general audience with a novice understanding of biology. Through a collaborative effort with authors of existing high-school and college-
level concept inventories, a new concept inventory was written, tested and revised to provide a tool to guide middle school teachers in analyzing their students misconceptions and informing their instructional decisions.
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**Background**

On a daily basis, newspaper headlines are filled with scientific debates on topics ranging from global climate change to stem cell treatments. The dilemmas we face require an unprecedented need for a scientifically literate society. We must cultivate a populace that understands the issues, can evaluate the scientific merit in evidence presented, make informed choices, and find solutions. A closer look at science education finds the current system failing to meet students’ needs at all levels, from kindergarten to college; and while our need for science literacy increases, students lack adequate scientific background to engage in these debates in a meaningful way (AAAS, 1993; National Research Council, 2006). This disconnect has been the driving force behind the emphasis placed on investigating new solutions to how we educate and prepare students in the fields of science, technology, engineering and mathematics (STEM) and the push towards integrating inquiry-based experiences within traditional modes of instruction that more closely mirrors the critical thinking that is key to STEM fields (Committee on Science, Engineering and Public Policy, 2007; Miller, 2009; Kuenzi et al., 2006; Banilower et al., 2013).
Shortfalls of Science Education

There has been a growing demand for increasing teacher accountability for student achievement through the use of state-mandated testing (Cavanagh, 2004). Schools largely are evaluated based on scores from multiple-choice tests, such as the California Standards Test (CST). Schools in the lowest 10% are classified as “Challenge Schools” and are slated for major restructuring, restaffing or school closure if significant progress is not seen within a three year period (U.S. Department of Education, 2010). In urban school districts, where achievement levels are historically in the lowest quartile, the possibility of school closure is a real threat. School administrators are under pressure to make sure that teachers are following the state standards and covering all the material that will be tested. The result has been to prioritize reading, writing and math, the only subjects in which California’s students are tested up to 5th grade.

As we progress to the middle and high school classrooms, pressure to perform on state-mandated tests has left its mark by influencing the way in which science is taught. A large body of research has demonstrated the
effectiveness of inquiry-based instruction in science classrooms; and yet, a small minority of teachers adopts this pedagogical approach (Capps & Crawford, 2013; Alberts, 2009). The pressure to perform well on state-mandated tests is cited as a key deterrent for teachers to integrate more inquiry-based instruction in their classrooms (Cavanagh, 2004). Teachers face the conflict of content depth versus breadth, i.e., whether to rush through content to cover all the standards or to allot the time needed to delve deeper into content. In the years leading up to the adoption of the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013), the state content standards were very comprehensive and required a fast teaching pace in order to cover all the content; thus, secondary teachers felt that there was not enough time to include inquiry-based instruction in their classrooms. As a result, ineffective teaching practices that emphasize rote memorization of definitions and processes without meaningful learning prevailed (National Research Council, 2012; Alberts, 2009; Schoon, 1998).

The result of inadequate science teaching is apparent at the university level. Professors complain that undergraduates, both science majors and nonmajors, are
arriving to college with gaps in their knowledge and with many misconceptions of basic scientific concepts (Olson & Labov, 2009). The lecture format most common in large, introductory classes does little to dispel these misconceptions and further perpetuates a scientific illiterate society. At many large universities, research productivity outweighs teaching effectiveness in tenure decisions (Brainard, 2007). With many demands on professors’ time, teaching is a low priority and the efficiency of lectures wins. Taken as a whole, the result is a cumulative failure of science education at every level compounded by the lack of preparation and meaningful, contextualized science in the K-20 educational continuum.

Improving Teacher Effectiveness

Teacher effectiveness has been shown to be one of the most significant determinants in increasing student achievement. Three of the key variables of teachers’ qualifications that highly correlate with student achievement are: (1) subject matter/content knowledge (Paige, 2003), (2) pedagogical content knowledge (Hill et al., 2005), (3) and teacher attitudes towards science (Lee & Krapfl, 2002).
**Content knowledge.** It seems obvious that a teacher should have a deep understanding of the content they are teaching. However, this is not always the case and an issue that plagues math and science education. Poor content knowledge is especially problematic in the primary grades, where the majority of teachers do not have a math or science degree (Banilower et al., 2013; National Research Council, 2007; Kuenzi et al., 2006).

While most undergraduates, even non-science majors, are required to take at least one biology class as part of their undergraduate coursework, the limitations of the predominant lecture-style format leaves them ill-prepared to teach science concepts especially in the emphasized inquiry-based format. Lecture-style classes have been shown to favor rote memorization of facts with little understanding of how the details relate to one another. Without repeated exposure, nor practice within a meaningful context, retention of the information is low, resulting in college students with little factual knowledge and poor conceptual bases for the content (Knight & Wood, 2005). Research on addressing misconceptions in the sciences suggests that a new concept cannot be learned until a student is forced to confront the limitations or
inconsistencies of underlying misconceptions (Guzzetti et al., 1993). Students persist in their erroneous beliefs, because these beliefs seem more reasonable or useful to them than the correct scientific concepts (Garvin-Doxas et al., 2007; Novak, 2002).

“We use current knowledge structures to help to assimilate new ones more rapidly. To the extent that current beliefs are true, then, we will assimilate further true information more rapidly. However, when the subset of beliefs that the individual is drawing on contains substantial amounts of false information, knowledge projection will delay the assimilation of the correct information” (Stanovich, 2009, p.159).

Teachers with a novice understanding of scientific concepts are unable to correct their students’ misconceptions and, consequently, perpetuate incorrect information. Without a learning environment conducive to challenging these misconceptions, errors in scientific fact and process persist. Universities across all science disciplines need to use more effective teaching practices, such as inquiry-based strategies, to ensure that their graduates attain a base level of conceptual understanding of science.

The problem of poor content knowledge persists at the secondary level, particularly in chemistry and physics where there are few teachers who hold degrees in these
disciplines (Banilower et al., 2013; National Research Council, 2007). Studies have cited low pay and a negative perception of teaching as key deterrents in recent college graduates not considering teaching as an option (Otero et al., 2006). However, several innovative programs at universities have been implemented to change those views and encourage recent chemistry and physics graduates to pursue teaching as a profession (Mervis, 2000; Otero et al., 2006, Stewart et al., 2013). For example, The Opportunity Equation, a report funded by the Institute for Advanced Study Commission on Mathematics and Science Education, calls for universities to take an active role in building professional partnerships with K-12 schools in order to share resources and knowledge (Miller, 2009). More coordinated efforts between K-12 and universities will continue to have a positive impact on increasing the content knowledge of teachers.

In the past few years, California State University East Bay (CSUEB) has taken an active role in improving science education in the K-12 classrooms by designing and implementing innovative programs to foster partnerships between the university and neighboring school districts. Several programs, such as NASA Lift-Off and Integrated
Middle School Science (IMSS) Partnership, have science professors in biology, chemistry, physics and earth science teaching content to middle and high school science teachers during summer institutes. Teacher participants work in collaboration with university faculty to design inquiry-based lessons for their students that clearly demonstrate relevant concepts. The Foundational Level General Science (FLGS) program targets primary school teachers (K-5) that lack a strong science foundation and work to deepen their content understanding through participation in four quarters of science instruction aligned to California state science standards. These programs, and other similar ones, use the intellectual capital available at the university to invest in the development of teachers' content knowledge, thus directly impacting their students' nascent understanding of science.

**Pedagogical content knowledge.** Pedagogical content knowledge involves knowing how to teach in a subject area such that concepts are effectively conveyed from teacher to student. It includes knowing how to choose the best examples, representations, and teaching activities to engage students in a meaningful way. In addition, it requires knowing common misconceptions held by novices and
how to remedy them (Shulman, 1986). The American Association for the Advancement of Sciences (AAAS, 1993), the National Academy of Sciences (Olson & Loucks-Horsley, 2000), and the National Science Teacher Association (NSTA, 2004), for example, emphasize that inquiry is key to understanding science. Time and again, many experts point to utilizing more inquiry-based instruction at all levels in our educational system as a solution to improving science education (AAAS, 1993; Duit & Treagust, 2003; Handelsman et al., 2006; Kuenzi et al., 2006; Brandon et al., 2008; Alberts, 2009).

Inquiry-based lessons are shown to be superior models of instruction, yet many K-12 science educators have not readily embraced it, and observations have shown that it is mostly absent in science classrooms. Many studies have focused on barriers that prevent primary teachers from integrating science into their daily practice (Appleton, 1999; Choi & Ramsey, 2009; van Driel et al., 1998). One such barrier is the pressure to perform well on state mandated tests, which has caused schools to prioritize reading and mathematics instruction over science. In addition, the majority of primary teachers do not have a science degree and lack pedagogical content knowledge
resulting in self-doubt in their ability to teach science. Another obstacle is that inquiry-based science instruction is perceived as requiring more supplies and preparation time than other subjects.

More work needs to be done by credentialing programs to prepare new and veteran teachers to overcome these obstacles and embrace this method of teaching (Anderson, 2002). If we are to make gains in science education, teachers must teach using evidence-based best practices that have been shown to increase student engagement, lengthen retention, and develop deeper understanding of the content (Hassard, 1992; Halme et al., 2006).

At the university level, the push for professors to become more effective at communicating their expertise is met with much resistance (Brainard, 2007). There is mounting evidence that supports the replacement of the typical lecture-based instruction in favor of more interactive pedagogy (Bransford et al., 2000; Handelsman et al., 2006; Hake, 2007; Knight & Wood, 2005). Increased funding from the National Science Foundation (NSF) is encouraging professors to embrace findings from educational research and incorporate more student-centered and engaging
lessons as part of their instruction (Phillips et al., 2008; Marrs & Novak, 2004). Several course redesign projects aimed at integrating evidence-based instructional practices have been implemented at CSUEB with increases in students’ learning and engagement (Inouye, pers. comm., 2016). At all educational levels, there is a need for science teachers to look at the current educational research and implement instructional methods that are most effective at getting students to understand the content.

Teacher attitudes. While there are many barriers (e.g., budget constraints, lack of supplies, etc.) to implementing reform movements, underlying cultural beliefs can be one of the most challenging obstacles to overcome (Anderson, 2002). Educators at all levels need to undergo a paradigm shift in order for real change to occur. For instance, if a teacher believes in the supremacy or efficiency of a book-centered approach, then it is unlikely that teacher will make pedagogical changes towards more hands-on teaching methods. Future teachers are likely to mirror the practices that they experienced themselves as a student, as there is an inherent discomfort in using a different and unfamiliar approach. School administrators should provide more professional development opportunities
for training and teachers to implement inquiry-based practices. In addition, there is a need to confront the negative perceptions of inquiry-based lessons such as them being too time-consuming and requiring more resources. Collaboration has been shown to be a useful way to help change teachers’ views and help with large-scale implementation projects, but there needs to be sufficient time allocated to university and K-12 teachers alike into working out the difficulties that are an inherent part of developing a new curriculum (Seymour, 2002).

The likelihood that a primary teacher will teach science depends largely on their own preparation and confidence in science (Banilower, et. al., 2013; Capps & Crawford, 2013; Appleton & Kindt, 1999). This problem is especially important at the primary level where teacher’s self-efficacy related to teaching science is typically low. Self-efficacy is defined as the belief held by an individual that they are capable of learning, or teaching, material (Baldwin et al., 1999). Teachers with high efficacy rates tend to prioritize science and are more likely to seek out and use inquiry-based teaching practices (Czerniak & Schriver, 1994). Conversely, teachers with low efficacy rates tend to utilize less effective science
teaching practices and minimize the time allocated to science (Ramey-Gassert et al., 1998). Many teachers in the second group recalled negative experiences in their personal educational history that influenced their attitudes towards science. It has also been shown that teachers with low self-efficacy scores tend to hold a greater amount of scientific misconceptions (Schoon & Boone, 1998). While it has been shown to be difficult to change a person’s attitude toward science, there has been some success with teacher preparation programs that engage pre-service teachers in experiential activities and provide them ample opportunity to practice effective science teaching with their peers and during student teaching placements (Cantrell et al., 2003). In addition, continued collegial and administrative support at the school site and availability to resources are key determinants in increasing self-efficacy rates among teachers (Ramey-Gassert et al., 1998; Smith, E. et al., 1993; McDevitt, T. et al., 1993). The Hands On Science Teaching (HOST) Labs at CSUEB are exemplary models of how to provide undergraduate students with first-hand experience teaching inquiry-based science lessons to visiting middle school students while countering perceptions of how science is taught. Through a
supportive environment, undergraduates develop their teaching skills and increase their confidence in their ability to teach science. Feedback from the pilot year has been overwhelmingly positive from all stakeholders, and participating undergraduates from a variety of majors have expressed interest in pursuing teaching careers (Jensen, pers. obs., 2016).

**Assessing Science Misconceptions**

Another major barrier to student achievement is the incorrect prior knowledge, or misconceptions, that students bring to a content area. Misconceptions are students’ own perceptions of scientific phenomenon based on previous teachings and their own observations of the natural world (Richardson, 2005). Because of the pejorative implication of misconception, some advocate for the use of the term “alternative conception” to reflect the continuum of understanding one can have of a concept (Gilbert & Swift, 1985). Learning is an active process in which students construct new knowledge in light of their prior conceptions. A discrepant event or new information that conflicts with this held view produces conceptual conflict though dissatisfaction with the extant belief and results
in the formulation of the scientific conception (Guzzetti et al., 1993). Students with a novice understanding of material can attain new factual information, but it requires an expert’s understanding to see the interrelatedness between discrete facts. When students learn new content, it is integrated into their existing knowledge base. When misconceptions exist, the new information may be distorted to fit the alternate or correct conceptions a student holds. It is essential for a teacher to be aware of existing misconceptions, so that they can directly challenge and revise them and foster a more accurate understanding of a topic in their students. Concept inventories are useful tools that have been developed as a diagnostic tool to identify and monitor retention of misconceptions in order to inform changes in teaching practices.

A concept inventory is a multiple choice format test that can readily assess student misconceptions in a specific content area. For each question, there is a set of distractor responses representing different misconceptions commonly held by students. Each question on a concept inventory should address only one concept, and ideally, should be asked in more than one context. Teachers can
administer a concept inventory at the beginning of a unit of study to determine which misconceptions are held by students and design interactive lessons for students to revise their understanding of the material. At the end of a unit of study or course, the teacher can administer the exact same test to look at the efficacy of specific lessons and strategies in changing students’ misconceptions or changing their alternative conceptions.

The first concept inventory, the Force Concept Inventory (FCI), was developed in the mid-1980s by Eric Mazur, a physics professor at Harvard University, and catalyzed a shift in science pedagogy (Halloun & Hestenes, 1985). Professors who perceived themselves as effective educators were dumbstruck by the data yielded by the FCIs that showed their students did not comprehend fundamental concepts from their courses. Confronted with these data, they tested various teaching strategies that emphasized active learning and engaged students in problem solving and application of content within the lecture (Hake, 2007; Richardson, 2005). Using the concept inventories, while confronting persistent misconceptions, the professors were able to gauge the effectiveness of these teaching practices as gains in student achievement.
Concept inventories have been developed and successfully integrated into introductory college courses in many different science disciplines; however, biology faculty have struggled to create a broad based assessment for use with introductory biology students. The exponential growth in the field of biology has resulted in many discrepancies about what is taught to introductory biology students at various universities. With such a broad range of topics that may be covered in an introductory biology course, it is nearly impossible to devise a reasonably short assessment that encompasses all of the possible content. As a result, many different concept inventories have been developed for specific concepts in biology, such as host-pathogen interactions (Marbach-Ad et al., 2009), natural selection (Anderson, 2002), or genetics (Smith et al., 2008). A broader use of concept inventories at all educational levels could be a valuable tool to inform and guide instruction.

This thesis project consists of two major components that will be discussed separately. The first part involves the development of a teacher preparation course aimed at improving K-8 teachers’ content and pedagogical knowledge, and the second involves the development and validation of
an assessment tool to monitor teachers’ shifts in their conceptual understanding of biology. By targeting a teacher population that has been shown to have the lowest self-efficacy and foundational understanding of science content (Schoon & Boone, 1998; Kuenzi et al., 2006), the FLGS courses aim to deepen teachers’ understanding and confidence in teaching the content. The creation and refinement of the Life Science Concept Inventory provides middle school teachers with an age-appropriate tool to help reveal commonly held misconception by their students so that they can be directly addressed through inquiry-based explorations of the content. Together, these projects demonstrate ways in which universities can play a direct role in improving the preparedness of future college students and contributing to a more scientifically literate populace.
Methods

FLGS Program Design

The FLGS program was established by science and science education faculty members at CSUEB, alongside engineers from the Bechtel and Broadcom Corporations, with funding from the Bechtel Foundation, in order to design a standards-aligned, four-course sequence of study aimed at improving science education in K-8 classrooms. The program targets pre-service and in-service teachers seeking a supplemental authorization in the state’s Foundational Level General Science Credential. FLGS participants enroll in four quarters of content coursework with each quarter focusing on a new science content area: chemistry, physics, biology and earth sciences. The content courses are hybrid courses including an online lecture component and an in-person weekly laboratory session. Each department designs and implements the lecture and laboratory sessions independently, with the common goal of FLGS participants mastering the content in order to pass the California Subject Examination for Teachers (CSET) General Science Tests. FLGS participants also enroll in two science teaching methods courses to further develop pedagogical
content knowledge and apply science content within inquiry-based, engineering-centered curricula.

The CSET tests are a series of standardized tests offered through Educational Testing Services (ETS) for various content areas that are used to assess subject matter competency. For a foundational science supplemental authorization, teachers must pass two subtests. Subtest 1 covers earth science and physical science, and Subtest 2 covers life science and chemistry. Teachers are required to pass both subtests in order to show mastery of the content area and meet the subject matter competency for credentialing requirements. The FLGS courses are designed to improve their content knowledge and as preparation for the CSET general science tests. As of Spring 2016, the FLGS courses at CSUEB are in the midst of an approval process by the California Commission on Teaching Credentialing (CTC) to be part of the waiver program, whereby students can demonstrate subject matter competency by taking a series of classes in lieu of a test.

The initial target population for the FLGS program was credentialed teachers who were working to add a supplemental authorization in foundational science. All the
FLGS participants held a multiple-subject credential that allowed them to teach all subjects in K-8, but in order for teachers to be eligible to teach single subject classes (e.g., a 7th grade life science class), they needed to obtain a supplemental authorization from the CTC. In addition to subject matter competency exams, teachers seeking a supplemental authorization in general science are required to take two quarters (a total of five quarter units) of subject matter pedagogy. FLGS participants enrolled in two quarters of course work (Science Methods courses) through the Teacher Education department at CSUEB especially designed for the cohort. Each class met weekly in person and emphasized the integration of inquiry-based teaching.

**Scope and Sequence of FLGS Biology Courses**

One of the four FLGS courses focused on biology. An online lecture component (BIOL 3011) and an in person weekly laboratory section (BIOL 3012) were first offered during the Spring 2011 quarter. BIOL 3011 was taught by a tenured biology professor at CSUEB, Dr. Caron Inouye, and the in-person laboratory section was taught by me, her graduate student. We collaborated closely in the
development of an aligned lecture and lab that would provide FLGS participants with the content understanding and teaching skills needed to improve their biology instruction and prepare them for the passage of the CSET Foundational General Sciences exams—Subtest 1 (test code 118) and Subtest II (test code 119).

The scope of the course was designed to align to both the California life science content standards for grades K-8 (California Department of Education, 2000) and the content covered on the CSET exam. For each grade level, from kindergarten to 8th grade, each content standard relating to biology was identified and categorized by major themes and concepts within the design of the course. In addition, the information released by ETS on the CSET Foundational General Science tests was reviewed to determine emphasis placed on each topic as measured by number of test questions related to each topic. Using these two pieces of information, learning objectives were written to encompass the content and depth of knowledge needed for mastery. As one measure of course effectiveness in preparation for the CSET, passage rates on the CSET Foundational Level General Science Subtests were collected.
The learning targets were thematically grouped into a ten-week time frame (equivalent to one quarter) and sequenced to best support student learning. Based on the fact that students had a strong foundation in chemistry (from taking the FLGS chemistry courses in the previous quarter), the course began with biochemistry and molecular biology content. Using DNA mutations as an entry point to evolutionary change, we used evolution as the link between molecular biology and ecology. The quarter ended with material dealing with human and plant physiology.

Using the course learning objectives, content was organized into a scope and sequence for BIOL 3011 and BIOL 3012. The instructors wanted to ensure cohesion between the online lecture and in-person laboratory section, so lab activities were designed to directly relate to that week’s online lecture content and provide opportunities to deepen FLGS participants’ understanding of content.

Prior to designing the laboratory sessions, a meeting was held to vet four selected lab activities by a panel of engineers from Broadcom and Bechtel, and CSUEB science faculty from the biology, chemistry, geology, physics and engineering departments. The Bechtel engineers in
particular provided feedback on how to integrate engineering practices into the lab activities, which informed revisions to the lab activities prior to FLGS course instruction. The panel randomly split into smaller groups consisting of 4-5 engineers and CSUEB faculty members to complete one of the four FLGS lab activities. After a brief introduction by the lab instructor, each group read the lab instructions and used the materials provided to complete the activities and answer the associated questions. At the end of an hour, each small group shared their experiences and the group as a whole provided constructive criticism on how to improve the effectiveness of each activity.

The online course was organized into asynchronous, weekly modules organized around a central concept. Each module included online lectures, associated reading assignments and weekly quizzes to monitor student progress. Online lectures were presented as a voice recording over a PowerPoint presentation compiled by the instructor and captured using Panopto software, all posted on the Blackboard course management platform. The assigned readings were relevant sections of chapters selected from *Campbell’s Essential Biology with Physiology, 3rd Edition*
(Simon et al., 2009). The instructor created formative quizzes using online test banks provided by Pearson Publishing in the Mastering Biology platform. FLGS participants were given the opportunity to take the quizzes multiple times with slight point deductions for each re-test with the goals of providing them with the opportunity to self-monitor their grasp of the content and as a diagnostic tool for the instructor.

In addition, summative assessments were incorporated into the online lecture series. An online midterm and non-cumulative final exam using some multiple choice questions from the publisher’s test bank in addition to some open-ended questions written by the instructor to assess deeper content understanding. Exams were made available online on Blackboard for a three-day period, and FLGS participants were required to take the timed exam in one sitting.

FLGS participants worked on a project called an “instructional case” over the course of the quarter. The project was aimed at FLGS participants identifying a common misconception held by their students and designing a series of lessons that would help their students develop a better understanding of the content. Discussions during the in-
person lab session and explicit teaching of misconceptions in the online lectures helped to inform FLGS participants’ understandings of common misconceptions held by middle school students. The instructional cases provided an opportunity for FLGS participants to apply their understanding to their own classroom instruction. FLGS participants were provided with a template and grading rubric created by the instructor to guide the design of their instructional cases. The instructor graded all instructional cases using the rubric provided.

The laboratory course required regular attendance and active participation. FLGS participants were expected to fully engage in all of the lab activities and complete associated written assignments. Each lab activity was designed by the instructor to enrich FLGS participants’ understanding of the related weekly content and model effective pedagogical strategies. All of the lab activities were designed by the lab instructor de novo or adapted from existing curricula. The majority of the lab activities had been field-tested in middle school classrooms and were aligned to support California science, math, and English language content standards. Lab activities were designed to support college-level learning while being adaptable for
any K-8 classroom with readily available materials. An accelerated pace, completing several activities in one lab session that would normally be taught in one to two weeks period for a typical middle school classroom, maximized the exposure to a variety of activities. In each lab meeting, time was allotted for discussion of how the lab activities could be modified to meet the learning needs of different age groups and/or student populations in terms of classroom management and cognitive development.

At the end of the quarter, a meeting was held with the same panel of engineers and CSU faculty in order for instructors that designed the biology laboratory exercises to share data from the FLGS cohort and reflect on the teaching experience.

Laboratory assessments related to content-specific skills were incorporated and modeled for FLGS participants. Some technical skills required a performance-based assessment or application-type questions to ensure mastery. For example, students were introduced to proper microscope use and then assessed using a microscope practicum whereby the instructor observed them preparing and focusing a wet mount slide. These types of authentic assessments were used
to monitor attainment of specific scientific skills (e.g., microscopy) and to ensure FLGS participants had the expertise to teach these skills to their students.

An in-depth explanation of the content, beyond the level of detail required for K-8 mastery, and discussion of management techniques was embedded into the lessons. For example, FLGS participants were shown a “Microscopy License” resembling a driver’s license. After having passed the practicum, students would present these to the teacher to checkout microscopes as a way to reinforce the special handling techniques required for proper use. These management discussions ensured FLGS participants had the capability and confidence to troubleshoot potential problems that may arise in their own classroom instruction.

Formative assessments were used throughout the laboratory course to monitor conceptual understanding. Oral questioning strategies, written responses to lab activity questions, and in class discussions and problem solving were routinely used to reveal the level of understanding of content. The lab instructor would ask probing questions and guide discussions in order to get FLGS participants thinking about how the lab activity
related to theoretical content. For example, during the study of cell biology, students enacted organelle’s functions by simulating a “classroom cell” where each person completed a specific task towards the creation of Lego block “proteins.” At one station, the person acting as the mitochondria simulated energy production by providing a piece of candy to the various people completing work throughout the cell. The simulation and related discussion helped FLGS participants to deepen their understanding of how cell organelles are interconnected and interdependent in a way that would have been difficult from readings. When a misconception was revealed, such as animal cells do not extract energy from their own cells, we would reference the simulation and further explore the source of misunderstanding and reframe the idea in a scientific context. All written responses to these formative assessments were scored and written feedback was provided to explain correct responses. FLGS participants were given time to read written feedback from the previous week’s assignment and ask clarifying questions.

Two diagnostic assessments, in the form of pre- and post-concept inventories and pre- and post-attitudinal surveys, were administered in paper and pencil form during
the first and last laboratory session. The Life Science Concept Inventory (discussed in more detail below, Appendix) monitored shifts in conceptual understanding in key topics in biology. It consisted of 32 multiple-choice questions. Each question had 4 or 5 responses wherein each response correlated to a different common misconception. Results of the pre-tests were used to help design lecture topics and lab activities that emphasized common misconceptions held by FLGS participants. A paired t-test was used to analyze each item on the pre- and post-concept inventory to identify any significant shifts in conceptual attainment. The 2012 FLGS cohort were given the second version of the Life Science Content Inventory (LSCI, V.2), which had been reduced to 23 questions with minor changes in the wording and response length.

The attitudinal survey was an adaptation of the CLASS survey, a validated assessment tool designed for studying shifts in students’ beliefs and attitudes towards astronomy (Zeilik, 1999). The language in the survey was changed from a focus on astronomy to a focus on biology. There were 34 statements provided on which FLGS participants ranked their level of agreement on a scale from 1 (strongly disagree) to 5 (strongly agree). The statements probed their feelings
towards biology as a subject and their ability to learn and teach biology. A paired t-test was used to compare FLGS participants’ mean pre-test and mean post-test scores on each item in the attitude surveys in order to identify any significant shifts in the FLGS participants’ beliefs and attitudes about biology.

**Creation, Validation, and Refinement of a Life Science Concept Inventory, (LSCI, V.1)**

A concept inventory is a diagnostic tool comprised of multiple-choice questions in which each of the distractors represents a common misconception (Richardson, 2005). The first step in development of the Life Science Concept Inventory (LSCI) was to choose which content to include. All of the California State Science Standards dealing with life science concepts for grades K-8 were compiled and aligned to the National Science Educational Standards (NSES). Based on a high degree of overlap or reoccurrence between the sets of content standards, three major themes were identified: central dogma, evolution and transfer of energy.

Collaborations were forged with authors of existing, validated concept inventories (Anderson et al., 2002; Korb,
2009) to develop a pilot version of a concept inventory (LSCI, V.1) that would be administered to middle school students. Using the existing concept inventories from collaborators, potential questions were selected that aligned with major themes identified in content standards. This subset of questions provided the basis for the development of an age-appropriate tool. Responses were modified and/or constructed using databases with lists of common misconceptions and firsthand teaching experiences (AAAS, 2016; Jensen, pers. obs., 2014).

The language of the set of questions was further modified to be appropriate for a younger, i.e., middle school, audience than the university level population for which the LSCI was originally intended. Some of the changes involved: rewriting questions using shorter, simpler sentence structure; balancing the length of the response options; using similar sentence structures for each response; asking questions in a more direct form; using more basic vocabulary; and omitting technical language. In addition, diagrams were included whenever possible to strengthen the context of the question and make the language more accessible to middle school students.
During the early implementations of the concept inventory, the goal was to elucidate students’ thinking about a concept, and a three-tiered model was applied (Smith & Tanner, 2010). The first tier is the multiple-choice question format. The second tier is an open-ended question that is designed to elucidate students’ rationale behind choosing a response. The third tier has a student rate his or her confidence in that their response is correct.

As part of the revision process, the pilot version of the LSCI (LSCI, V.1, 2011-2012) was administered to the FLGS participants. Their open-ended responses helped inform which questions needed to be modified for clarity. FLGS participants were questioned in one-on-one interviews at the end of the quarter to probe their thinking underlying their incorrect responses in order to better understand the source of their misconceptions. Each interview was videotaped to capture the exact language. The videotapes were reviewed and common themes were noted. The feedback from these interviews was one source of information to drive the revision of the pilot concept inventory.
A quantitative analysis of the FLGS participant responses was used to determine item difficulty and item discrimination. Item difficulty (P-value) is simply the percentage of people who chose the correct answer. Item Discrimination (D-value) is a measurement of how well a question can discriminate between high and low performers. The first step is to tabulate the number of correct responses and rank the scores from low to high. The bottom third of the test takers creates a “low performing” group, the top third creates a “high performing” group, and the remaining represent the “middle performing” group. To calculate the Item Discrimination (D-value), the following equation is used:

\[ D = \frac{(\text{#high performers correct responses}) - (\text{#low performers correct responses})}{\text{# of members in the largest of the two groups}} \]

A high D-value indicates a strong ability to discriminate between the two groups and small (or negative) value suggests a poor ability for a question to discriminate between the two groups. An item where everyone either gets the answer correct or incorrect has a value of zero.

Using the data collected from administering the pilot version (LSCI, V.1) to guide revision, questions were either removed from the test or rewritten to incorporate
the language that seemed consistent with the understanding gained from the FLGS participant interviews.

Revision and Validation of a Life Science Concept Inventory (LSCI, V.2)

The revised concept inventory (LSCI, V.2) was used for the Spring 2012 FLGS cohort as a pre- and post-assessment tool. In addition, LSCI, V.2 was one tool used to help monitor shifts in misconceptions as part of the Integrated Middle School Science (IMSS) program. The IMSS teachers represent a different teacher demographic group than the FLGS participants. All of the IMSS teachers hold a Single Subject credential in Life Science and have been teaching life science at the middle school level.

The IMSS teachers were given the LSCI, V.2 with a two-tiered option (multiple choice responses and an open-ended response for them to explain their rationale) at the beginning of a two-week long summer institute. The results helped CSUEB faculty members guide summer institute content work and design discussions around commonly held misconceptions. In addition, the IMSS teachers’ open-responses provided valuable feedback in the revision process.
Following the summer institute, each of the IMSS teachers administered the LSCI, V.2 to each their middle school life science classes. The LSCI, V.2 was divided into three thematic sections, and teachers had the option of giving the test in its entirety or administering the test as sub-tests before and after a unit of study. The student responses were recorded on a Scantron sheet, collected and analyzed by the CSUEB testing center. The data from each IMSS teacher’s class were compiled into a stacked graph to show the distribution of responses. Since each response relates to a different commonly held misconception, a graph of this type is very helpful to visualize the commonly held misconceptions by their students. During a fall in-service training, IMSS teachers were given the opportunity to look at their class’ data and cross-reference the results with the tests in order to discuss misconceptions widely held across all students, as well as looking at their individual students’ work.

Several IMSS teachers (N = 17) administered at least one part of the two-tiered LSCI, V.2 (with the open-ended format) to their students (N = 330). Student responses were collected from IMSS teachers and read by three experts in the field. For each response, the students’ open-ended
response was assigned a number to gauge the level of understanding. A misconception was assigned a negative value while a correct explanation was assigned a positive value. The totals for each response indicated the level of misconceptions held within a group of students.

Using these data, along with feedback from a focus group of IMSS teachers and concept inventory collaborators, a third version of the concept inventory (LSCI, V.3) was developed. This third version was administered to the 2012-2013 cohort of FLGS participants. The LSCI has continued to evolve and be revised. It is currently in its fourth iteration.

Results

FLGS Course Participants: Concepts and Perceptions

FLGS participants enrolled in the FLGS Biology courses (BIOL 3011/3012) for Spring 2011 were given several assessments at the beginning and end of the quarter to monitor changes in biological misconceptions, confidence in
ability to answer content questions, and attitudes towards biology.

FLGS participants in the Spring 2011 cohort were given the Life Science Concept Inventory, Version 1 (LSCI, V.1) to monitor changes in biological misconceptions. The mean number of correct responses for the class was compared between the beginning and end of the quarter. In this version, FLGS participants were asked to complete two tasks for each of the 32 questions. Questions were grouped into three themes: Genetics, Evolution, and Energy Transfer. FLGS participants would first select a response in a multiple-choice format and then rank their confidence in their ability to choose the correct answer. The mean pre-test score ($\bar{X} = 18.3, \ SD = 3.72, \ N = 6$) was not significantly different from the mean post-test score ($\bar{X} = 17.8, \ SD = 3.43, \ N = 6$; paired $t = 0.50, \ df = 5, \ p > 0.05$; Fig. 1). In contrast, the mean confidence ranking showed a significant increase between the pre-test ($\bar{X} = 2.77, \ SD = 0.52, \ N = 6$) and post-test performances ($\bar{X} = 3.59, \ SD = 0.54, \ N = 6$; paired $t = -3.96, \ df = 5, \ p < 0.05$; Fig. 2).
Figure 1. Comparison of the mean number of correct responses on the 32-question Life Science Concept Inventory (Version 1) for the Spring 2011 cohort (N=6) enrolled in the FLGS Biology courses at the beginning (Pre-test) and end of the quarter (Post-test). Error bars represent ± 1 SD.

Figure 2. Comparison of mean confidence ratings on answers to 32 questions in the Life Science Concept Inventory (Version 1) for the Spring 2011 cohort (N=6) enrolled in the FLGS Biology courses at the beginning (Pre-test) and end of the quarter (Post-test). FLGS participants rated their confidence in a correct response on a scale from 1 (least confident) to 5 (most confident) to each question on the concept inventory. Error bars represent ± 1 SD.
FLGS participants were given the Biology Attitude Survey based on a previously validated survey in astronomy (Zeilik, 1999) to monitor changes in their attitudes and beliefs about biology and science. Questions were grouped into four categories to probe different areas: (a) FLGS participants' positive and negative feelings about biology, (b) attitudes about FLGS participants' own intellectual knowledge and skills when applied to biology, (c) attitudes about the usefulness, relevance and worth of biology in FLGS participants' personal and professional lives, and (d) attitudes about the difficulty of biology as a subject.

For each of the 34 statements, FLGS participants rated how much they agreed with each statement on a 5-point Liekert scale (1 = strongly disagree to 5 = strongly agree). The mean attitudinal ranking from the pre-test ($\bar{X} = 3.17$, SD = 0.20, N =6) compared to the post-test ($\bar{X} = 3.05$, SD = 0.21, N =6) showed no significant difference (paired t = -0.57, df = 5, p>0.5; Fig. 3A).

When the questions were separated by categories, the appeared to be trends in how the students perceive biology; however, there was no statistical significance between the groups. The category with the highest scores was Category
C: Usefulness, Relevance and Worth and the lowest scores for Category D: Difficulty of Biology as a Subject.

Figure 3. Comparison of the ratings in response to answers on a Biology Attitude Survey for the Spring 2011 cohort cohorts enrolled in the FLGS Biology courses at the beginning and end of the quarter. FLGS participants rated their agreement or disagreement towards statements about their attitudes towards biology and science on a scale from 1-5 (1 = strong disagreement, 5 = strong agreement). (A) Overall scores from the pre- and post-tests. Bars represent the average rating to each statement on a 34-question survey. Error bars represent ± 1 SD (N = 6). (B) The same responses to the Biology Attitude Survey separated by different question categories. Bars represent the average rating to each statement on a 34-question survey. Error bars represent ± 1 SD (N = 6).
A second cohort of students enrolled in the FLGS courses in Spring 2012 was given the Life Science Concept Inventory, Version 2 (LSCI, V.2) to monitor changes in biological misconceptions. The main difference between the two versions is that 10 questions were removed from the original version that were confusing or did not have the ability to discriminate between different groups. The data from the Spring 2011 cohort was edited and reanalyzed to compare only the questions that were tested in Spring 2012. Removing these 10 questions caused the mean to shift slightly in both the pre-test ($\bar{X} = 14.3, \ SD = 2.16, \ N = 6$) and post-test ($\bar{X} = 14.2, \ SD = 2.04, \ N = 6$), but still no significant difference was seen (paired $t = 0.19, \ df = 5, \ p > 0.05$; Fig. 4). The Spring 2012 cohort did only slightly better than the previous year and the mean pre-test ($\bar{X} = 15.7, \ SD = 3.29, \ N = 3$) showed no significant difference from the post-test ($\bar{X} = 15.7, \ SD = 0.58, \ N = 3$; paired $t = 0.5, \ df = 2, \ p > 0.05$; Fig. 4).
Figure 4. Comparison of the number of correct responses on the Life Science Concept Inventory (V. 2) for Spring 2011 and Spring 2012 cohorts of the FLGS Biology courses at the beginning (pre-test) and end (post-test) of the quarters. Bars represent the mean number of correct responses of 23 questions that were present in each exam. Error bars represent ± 1 SD (N = 6 for 2011; N = 3 for 2012).

CSET Passage Rates

One of the goals of the FLGS program is to provide adequate content knowledge for students to be able to pass the CSET General Science exam. The mean passing rates for the two cohorts are shown in Table 1 (N = 6 for 2011; N = 4 for 2012).
Table 1. Comparison of passage rates on the CSET General Science Exam for students enrolled in the FLGS Biology courses in Spring 2011 (N=6) and Spring 2012 (Korb et al., 2015).

<table>
<thead>
<tr>
<th>Cohort</th>
<th>Passing Rate (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spring 2011</td>
<td>66.7</td>
</tr>
<tr>
<td>Spring 2012</td>
<td>100</td>
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</table>

Creation and Validation of the Life Science Concept Inventory (LSCI)

The second major component of this work was the creation and validation of a life science concept inventory (LSCI) that could be used in middle school classrooms.

The first version of the Life Science Concept Inventory (LSCI V.1) was piloted with several different populations to accumulate enough data to provide adequate numbers for validation. The teachers enrolled in the Biology FLGS courses (n = 6), and a separate group of middle school life science teachers (n = 10) participating in the first year of the Integrated Middle School Science (IMSS) Program were tested. In addition, a group of middle school students from one of the IMSS teacher’s classrooms
was tested (n = 29). The responses from these three groups were used to inform of which questions needed to be revised for the next iteration of the concept inventory.

Questions were analyzed to determine the Item Discrimination (D-value) and Item Difficulty (P-value). A “very good” discriminator was defined to be a D-value above 0.40, a “good” D-value was in the range of 0.30–0.39, a “marginal” D-value as 0.2 – 0.29, and a “poor” D-value was below 0.19 or a negative value. The teachers’ (FLGS participants and IMSS teachers) and the students’ D-values were analyzed individually, and then compared to summarize whether the question could be considered good, fair or poor discriminators. When both student and teachers D-values were in the range for “very good” or “good” the question was defined as a good discriminator. For some questions all of the teachers answered correctly, so there was no difference between the low and high groups; however, there was a wider spread in the student responses. Since this concept inventory is aimed at a middle school student population, questions were also defined as good discriminators if there was a high D-value in the students and little or no difference seen in the teacher population. Similarly, a fair discriminator had both student and
teacher D-values fall within the marginal range with little or no difference in the teacher population but a fair range in the student responses. All other questions that fell below this range were considered poor discriminators.

The Item Difficulty (P-value) is calculated by determining the percentage of correct responses for each test question. For teachers (FLGS participants and IMSS teachers), means above 0.75 were designated as easy, in the range of 0.5 – 0.75 as moderate, and below 0.5 as challenging. For students who had less exposure to the content, the range was shifted to above 0.4 for easy, 0.3 – 0.4 for moderate and anything below as challenging. Teacher and student P-values were compared to summarize the difficulty of each question. When both fell within an easy range, or when the teacher was in the easy range and students were in the moderate range, then a question was designated as “easy”. The same was done for the moderate range, emphasizing the teacher responses over the students. Table 2 summarizes the P-values and D-values for the compiled teacher populations and student population for each question on the LSCI (V.1).

Table 2. Discrimination and Difficulty Values for each question on LSCI (V.1). Values are means (N=16 for teachers; N=29 for students). Each D-value was classified into a range of good (shown as green;
Each P-value was classified into a range of easy (shown as green; >0.75 for teachers and >0.4 for students), moderate (shown as yellow; 0.5–0.75 for teachers and 0.3–0.4 for students) and challenging (shown as red; <0.5 for teachers and <0.3 for students). Comparisons of teacher and student values were used to summarize the discrimination and difficulty of each question. Symbols adjacent to the question number indicate changes made in the next iteration of the LSCI. (*) represent questions that were removed entirely, (†) represents questions that were significantly reworded, and (‡) represents questions that were not modified in any way at the author’s request.

<table>
<thead>
<tr>
<th>Question Number</th>
<th>Discrimination (D-value)</th>
<th>Difficulty (P-value)</th>
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<tbody>
<tr>
<td></td>
<td>Teachers</td>
<td>Students</td>
</tr>
<tr>
<td>1</td>
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<td>0.52</td>
</tr>
<tr>
<td>2*</td>
<td>0.38</td>
<td>0.31</td>
</tr>
<tr>
<td>3*</td>
<td>0.75</td>
<td>-0.10</td>
</tr>
<tr>
<td>4*</td>
<td>0.00</td>
<td>0.31</td>
</tr>
<tr>
<td>5</td>
<td>0.19</td>
<td>0.52</td>
</tr>
<tr>
<td>6</td>
<td>0.38</td>
<td>0.21</td>
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<tr>
<td>7*</td>
<td>0.19</td>
<td>-0.10</td>
</tr>
<tr>
<td>8*</td>
<td>0.38</td>
<td>0.41</td>
</tr>
<tr>
<td>9</td>
<td>0.56</td>
<td>0.31</td>
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<tr>
<td>10*</td>
<td>0.56</td>
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<tr>
<td>11*</td>
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<td>Question</td>
<td>Discrimination (D-value)</td>
<td>Difficulty (P-value)</td>
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<tr>
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<td>Teachers</td>
<td>Students</td>
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<td>32</td>
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</table>

In addition, teachers enrolled in FLGS Biology courses were interviewed in a one-on-one setting to discuss their attitudes towards the course and to discuss their rationale.
in choosing selected responses on the LSCI, V1. FLGS participants did a "think aloud," in which they explained the mental process used in choosing a correct answer and eliminating incorrect answers. Through this process, misconceptions were probed through further questioning and differentiated from misunderstandings due to language or poor phrasing.

The data and interview feedback helped to guide our selection process in the creation of the second iteration, LSCI, V2. Ten questions were removed entirely either due to their inability to discriminate, their level of difficulty, or their poor alignment to the content covered by middle school classes (indicated by * in Table 2). Some questions were edited to ensure that every question had only 4 responses with balanced distractors, in terms of their phrasing and length. Others were significantly reworded, based on the interview feedback, to make them clearer (indicated by † in Table 2). A series of questions (#21-26) on population ecology and natural selection were not modified in any way at the request of the author, since these questions were being used in different trials and needed to be left unchanged for valid comparison (indicated by ‡ in Table 2).
Results from Middle School Students

Teachers participating in the 2011 IMSS Summer Institute professional development administered the LSCI, V.1 to their middle school life science classes at the beginning of the 2012-2013 school year. The results were compiled for each class, analyzed, and presented to teachers during an IMSS Fall professional development workshop. The compiled data were presented as a stacked graph to allow for teachers to observe both the percentage of correct responses and the distribution of incorrect responses (Fig. 5). For example, for Question #9 72% of the students chose the correct answer. The remaining students split their choices equally between the incorrect responses for A, B and C. The data presented were discussed during the workshop and used to guide discussions of pedagogical practices.
Figure 5. Responses to Life Science Concept Inventory (LSCI, V.1) compiled from IMSS teacher’s middle school life science classes. Bars represent the average number of responses to 23 questions from either LSCI, V.1 or one of three thematic subtests. (Genetics subtest N=330, Evolution subtest N=152, Energy Transfer subtest N = 112)

Conclusions

Impacts of the FLGS courses on teachers’ content knowledge

One of the main objectives of the FLGS course development was to deepen teacher’s content knowledge in science to better prepare them for teaching science to elementary and middle school students. The Life Science Concept Inventory was one tool used to track shifts in students’ conceptual understanding of biology; however,
little to no changes were observed in the 2011 nor 2012 FLGS cohorts when comparing responses from the post-assessment administered at the end of the course to the pre-assessment given on the first day (Fig. 1 and Fig. 4). Furthermore, LSCI, V.1 included a third tier in which the 2011 FLGS cohort ranked their confidence in their ability to choose the correct responses and the results showed a significant increase in confidence. In summary, the FLGS participants showed no difference in their conceptual understanding but believed that they had improved. This is troubling, yet consistent with other research (Prince et al., 2012; Yang & Miller, 2013; Thompson & Logue, 2006) that has shown how difficult it can be to shift students’ misconceptions. While the data didn’t show a significant change in students’ conceptual understanding, it was valuable for informing course design and revising the concept inventory.

After the initial teaching of BIOL 3011 and BIOL 3012, it was evident that we had to be more deliberate and explicit in addressing common misconceptions held by FLGS participants. The online lectures included slides reviewing commonly held misconceptions for each of the topics covered. This was reinforced by lab activities designed to
deepen students’ understanding and opportunities to explore any misconceptions. Additionally, the summative capstone experience was changed to an instructional case that required FLGS participants to research commonly held misconceptions related to the content they taught and to design or modify lessons that would directly address their students’ misconceptions. One FLGS participant modified an activity similar to one she had completed in the lab course that had helped her to better understand organelle structure and function. Similar to the cell simulation we did in the laboratory, she had her students enact different roles of the digestive system. By having students actively simulating the role each organ plays, she shifted a unit that had traditionally been reliant on vocabulary and memorization towards an engaging, memorable activity that better demonstrated each organ’s role. The instructional case provided an opportunity for FLGS participants to apply their understanding of misconceptions to their own classroom environments.

The interviews conducted at the end of the quarter provided feedback on the efficacy of the concept inventory. Questioning FLGS participants’ rationale for choosing a particular response on the LSCI helped to discriminate
whether some of the questions were misinterpreted due to language or phrasing or were actual misconceptions. Additionally, the interviews helped inform the LSCI revision process by mirroring simpler language used by FLGS participants to discuss a topic. Questions that remained too confusing or did not align to a held misconception were removed (Table 2).

In other instances, the concept inventory accurately revealed misconceptions held by FLGS participants due to partial or superficial understanding of the concepts. For example, Question 25 in the LSCI, V.1 was one of a series of questions focused on natural selection. It asked FLGS participants to think about the possible origin of different beak types in the Galapagos finches.

25. How did the different beak types first arise in the Galapagos finches?

a) The changes in the finches’ beak size and shape occurred because of their need to be able to eat different kinds of food to survive.

b) Changes in the finches’ beaks occurred by chance, and when there was a good match between beak shape and available food, those birds had more
babies.

c) The changes in the finches’ beaks occurred because the environment caused the desired changes in the finches’ DNA.

d) The finches’ beaks changed size and shape gradually with each generation, with some beaks getting larger and some getting smaller.

When the three FLGS participants who missed the question in the post-assessment were asked in a one-on-one interview to explain their thinking as they read the choices aloud, all three FLGS participants immediately eliminated the correct answer “B” as a choice not understanding the role that chance plays in natural selection. This reveals a basic misconception and lack of understanding of evolutionary processes. A portion of lectures that described natural selection discussed the common misconception of an organism “desiring” or “deliberately developing” traits required for survival. The associated laboratory activity dealt directly with chance. FLGS participants used binder clips to simulate natural selection of a crab’s claw over several generations. In the first iteration, students were given the same size and
shape in either black or silver. Students correctly concluded that any variations from one generation to the next were not a result of natural selection, but chance. In the second iteration, they saw that changing the size could give one group an advantage allowing that trait to accumulate in future generations. In the debrief, we discussed the different scenarios and how natural selection was present in the latter example. When reminded of this activity during the interview, they weren’t able to generalize their understanding to a slightly different scenario revealing a lack of depth of knowledge. Even with deliberate discussions and lab activities that directly simulated natural selection and the role chance plays, FLGS participants were unable to change their preconceived ideas of how evolution works.

Another question on the CI revealed how FLGS participants struggled to integrate and assimilate information presented at different organizational levels. Question 19 required students to connect aerobic respiration at a molecular level to respiration at an organismal level. Four of the six FLGS participants answered this question incorrectly on the post-assessment.
19. **The oxygen that we breathe in, ultimately ends up:**

a) Inside the tiny air sacs of our lungs.

b) Traveling through the bloodstream.

   Reacting with carbon to create carbon dioxide.

c)

d) Inside the mitochondria of our cells.

During interviews, all FLGS participants understood the role of the vascular system and the necessity to deliver oxygen to cells, but when pressed further they couldn’t explain why the cells would need oxygen. When asked directly, FLGS participants knew that the mitochondria were the sites of aerobic respiration and produced ATP for energy use in cellular processes. FLGS participants were able to memorize discrete processes and definitions, but a deeper understanding and the ability to connect content across topics and levels of organization was difficult and required multiple exposures and more opportunities to make connections.

Misconceptions are deeply held and difficult to change (Garvin-Doxas et al. 2007; Novak, 2002). Misconceptions are
the conclusions created to make sense of the natural world and often involve incorrect suppositions. Even when students are confronted with phenomena that directly contradict the misconception, their hardwired beliefs are difficult to change. After seeing little to no shift on the concept inventory from the 2011 FLGS cohort, we deliberately included more discussions of common misconceptions in our lecture presentations and during in-person lab activities. However, this did not significantly shift mean scores between the 2011 and 2012 FLGS cohorts (Fig. 4). Our results are consistent with other researchers in the field (Prince et al., 2012; Yang & Miller, 2013; Thompson & Logue, 2006). This calls into question whether or not concept inventories reveal such shifts.

One of the benefits of having teachers teach within their degree program major ensures they have had multiple upper division courses to build a deeper understanding of their content area. When students are exposed to topics only once, there is a limit to the depth of understanding they will be able to achieve. As with Question #19 regarding cellular respiration, FLGS participants struggled to connect concepts that were interrelated, but presented within different contexts in the course. As one of the FLGS
participants summarized, “The online portion provides background to feel comfortable teaching biology. But, I would still need to do more background the day before a lesson to really be able to teach well.” But, having been exposed to content that they had little familiarity with helped them to see the importance of major concepts they would have otherwise avoided. Several FLGS participants noted that they would place more emphasis on cellular and molecular mechanisms now that they understood how it related to other topics. The FLGS courses are part of a four-quarter series with some overlap between the content covered, so the spiraled nature of the content allows for multiple exposures. Global climate change, for instance, may be covered in biology, earth science and chemistry with a different emphasis depending on the content area. Ideally, the level of understanding FLGS participants have exiting the FLGS courses will provide them with a solid foundation allowing them to develop mastery as they repeatedly interact with the content and as they teach the topics to their students.

One of the goals of the FLGS courses is to provide FLGS participants with the content knowledge necessary in order to pass their subject-matter exams. Summative
assessments in the lecture course had a format similar to the CSET exams, a series of multiple-choice questions followed by a few open-ended responses. The difficulty of questions varied, but the assessments aimed to assess overall content knowledge. The summative assessments from the lecture course showed students did not have a strong mastery of the content. The average exam scores were 73.6% and 72.1% for the 2011 and 2012 cohorts, respectively. All of the FLGS participants were full-time teachers balancing their coursework with job responsibilities. Their primary motivation for taking the course was to deepen their understanding in order to pass the CSET exams. There was little repercussion to earning a lower grade, as long as they passed. It is impossible to compare the percentage scores from our assessments to the scaled scores of the CSET, but since the state is measuring competency and not mastery, a “C” level understanding is likely sufficient. The state average for passage rates on the Foundational Level General Science Subtests 1 and 2 is 82.4% (Taylor, 2014). Of the FLGS participants enrolled in Spring 2011, 66.7% passed their CSET, while the Spring 2012 cohort showed 100% passage rates (Korb et al., 2015). Improvements made to BIOL 3011 and BIOL 3012 in the interim year may
have contributed to the increase in passage rates between the two cohorts. This rate is well above the state’s average and, as such, one indicator of success of the FLGS program.

**Impacts of the FLGS courses on teachers’ attitudes**

Initial review of the CLASS attitude survey showed no statistically significant difference in mean scores between the pre- and post-assessments (Fig. 3). However, upon further investigation into the categories of questions, some interesting trends appeared. FLGS participants held the most negative attitudes toward the difficulty of biology and the most favorable attitudes towards its usefulness. FLGS participants felt the content was relevant to their daily lives and useful to study; however, they thought biology was difficult to master and was full of complex ideas. These beliefs were evident in some of the responses during the post-course interviews. “Discouraging,” “mortifying” and “not confident” were some of the words used to describe their self-perceptions of how they did on the concept inventory. While their confidence to specific responses showed a significant increase (Fig.
2), their overall tone used to describe their ability to understand the concepts was rather negative. Some of these attitudes may result in an additional barrier to deeply understanding and assimilating the concepts.

The laboratory portion of the class seemed to have the largest impact on shifting teachers’ self-efficacy. The overwhelming feedback from participants in the FLGS courses was how relevant and useful the lab activities were. Based on the end of term survey, all FLGS participants would highly recommend the courses to a peer. Their own engagement and enjoyment of the activities made them excited to bring the lessons back to their own classrooms. Two of the six FLGS participants had implemented some of the activities with their own middle school students during the duration of the quarter, and all FLGS participants said they planned to implement some of the activities with their students. One FLGS participant said that “having seen these hands-on activities showed me how I could teach these abstract concepts to my students.” Having firsthand experience gave them confidence in teaching that specific activity, but also allowed them to see possibilities for other content areas and lessons.
Impacts of the FLGS courses on teachers’ pedagogical content knowledge

Teachers need to understand their subject matter, but they also need to have specific pedagogical knowledge on how to best deliver the subject matter to their students. The FLGS courses were designed to model teaching strategies, assessments and lab activities that could readily be replicated in middle school classrooms. Although FLGS participants completed the lab activities at an accelerated pace, these activities were presented in a way similar to how they should be presented to middle school students. This allowed FLGS participants to gain an understanding of the lab activities from a learner’s perspective. Having this mindset allowed FLGS participants to identify specific sections that may be more challenging for their student populations and think through how to modify their instruction with differentiation embedded into the activities. Time was spent at each lab session to discuss and share ideas on making the content more accessible to English language learners, on adapting the lesson for younger or older students, and on how to meet
the specific needs of special education students in their classrooms.

The lab activities integrated various teaching methods to provide FLGS participants with experience in core scientific practices outlined in the Next Generation Science Standards (NGSS) (NGSS Lead States, 2013). Some of the embedded pedagogical content skills included: data manipulation, graphing, microscopy, observational drawing, experimental design, quadrat sampling, and Punnett square analysis. These content specific skills were blended with more general teaching strategies such as: modeling, questioning, and regular use of formative assessments. Explicit instruction of these strategies, followed by debriefs explaining the rationale and providing instructional pointers, allowed FLGS participants to make connections between pedagogical theory and practice.

All of the lab activities were tightly aligned with the lecture content. For example, if students were reading and learning about succession in the lecture, we’d spend a part of our laboratory section walking around the outside of the science building looking for disturbances in the landscaping and evidence of succession. Showing FLGS
participants real-world applications to the content helped to heighten their awareness and make "fieldwork" feel more accessible in a school settings. By having FLGS participants completing the activities they would be replicating with their students, they gained a much better understanding of the lab activity, in terms of the underlying content, familiarity with the techniques, and pacing and flow of the lab activities. This understanding made it much more likely that FLGS participants would implement the lessons in their own classrooms. In addition, the activities were designed, for the most part, to use everyday items that are easily obtained and cost effective for schools with limited supply budgets. Supporting documents and student worksheets were provided to FLGS participants to make implementation easier. Within one unit of study, there would be a multiple opportunities for students to build their understanding of a concept. Our goal was to have the FLGS participants leave the FLGS courses with an arsenal of activities that could be replicated in their classrooms and strategies to engage students in learning.

Many of the activities had a synthesis component that required students to share-out their understandings with
peers or in whole-class discussions. During these discussions, misconceptions were often revealed and provided an opportunity for how to facilitate a conversation that would shift thinking towards a scientifically accurate understanding. For example, a storyboarding activity involving the Central Dogma had FLGS participants organize a series of figures and add captions to explain what was happening on each card. After each group had an opportunity to work separately to create their own “story,” they compared their figure order and caption details with another group. By observing the peer interactions and storyboards, the teacher was able to assess levels of comprehension and reinforce concepts, as needed. One FLGS participant credited the FLGS course with having “increased my confidence to move away from the book and determine what was important.” Another FLGS participant predicted that she would be “less controlling when teaching and allow discussions on more topics because of better comfort level.” By modeling effective pedagogy, the FLGS courses were successful at helping its participants to increase their confidence in teaching science effectively and broadening their skill set.
Concept Inventory Development

The refinement of the Life Science Concept Inventory is ongoing and currently in its fourth version (2015). The lessons learned in early revisions helped to design questions where the language is clear and accessible to students. Not having much prior exposure to the content, the middle school students struggled with some of the more technical terminology. Being able to create scenarios that demonstrated the concept without including the actual terminology allowed us to probe student understanding without prior knowledge of a specific term. The challenge persists in finding a balance between precise descriptions while minimizing technical language. By using too simple of language, it is possible to oversimplify the concepts to the point where you are not accurately gauging students’ understanding. Questions that were too difficult, too vague or too readily misinterpreted were removed. Using quantitative data to help guide our decision making process of which questions to keep and which to revise helped to provide objectivity to the process (Fig. 2).
Ultimately, the concept inventory is a fast and efficient way to get a glimpse at a class’ conceptual understanding. A teacher can administer a multiple choice format exam at the beginning of a course and readily get feedback on which misconceptions their students have. The results from concept inventories are a useful tool to frame discussions and inform instruction. Their use in the IMSS professional development sessions helped teachers to design instructional cases that would ensure students had repeated exposure to concepts and were given opportunities to interact with the concepts from multiple perspectives (Fig. 5). In the FLGS courses, the instructors used the feedback to redesign the course to deliberately and explicitly address commonly held misconceptions. We changed the summative assessment for the 2012 cohort to have FLGS participants investigate how references to science in popular culture could reinforce biological misconceptions. Each FLGS participant had to find an example of an advertisement, dietary plan, or other biologically relevant topic that misrepresented or perpetuated a scientific inaccuracy. By having the FLGS participants do research on these topics, we hoped they would be more attuned to their
own misconceptions and their role in helping their students to be more scientifically literate.

The test creation and revision process also resulted in my own growth in writing assessments. The focus on language use, providing contextualized scenarios, balancing answer responses, and ensuring the questions are aligned to the content have all made me a better teacher and creator of more effective assessments.

Implications and the future of FLGS

Changing deeply held misconceptions is hard, but the scientific community is making significant gains in moving science instruction towards practices that aid in deeper learning. California’s adoption of Next Generation Science Standards (NGSS) (NGSS Lead States, 2013) demonstrates the willingness to move away from superficial learning of content towards a deeper learning embedded with sound science teaching practices. As state mandated testing begins to implement science assessments aligned to NGSS, the ability to track skills and content understanding in students will become available and will add pressure for implementing these practices. In the past, “teaching to the
test” had been a complaint of content standards; however, with new technology testing platforms allow for assessing more complex skills that are inherent to the NGSS. If teachers are “teaching to the test,” they will be teaching the skills that we want students to be able to perform.

Another recent shift in the K-12 education community has been the implementation of the Common Core State Standards (CCSS) (National Governors Association, 2010). The CCSS hold the expectation that all teachers integrate content literacy into their instruction. Science has content specific reading and writing tasks that are subject matter specific. Being able to instruct students on how to interpret and compose scientific writing is one of the skills that teachers need to learn. Integration of content area literacy has already been a minor thread of the FLGS courses, but more deliberate and explicit integration will help future science teachers to gain experience and comfort in teaching scientific literacy skills. So, in using formative assessment tools, such as a CI while probing misconceptions, teachers can assist students in providing deeper evidence for their written and oral contributions to a course. In this, students deconstruct and reconstruct
their alternative conceptions using inquiry-based activities.

The university’s support for and commitment to programs that develop better science instruction help to graduate students better prepared to be science teachers and a more scientifically literate populace. There have been efforts made within the Biology Department at CSUEB to improve the large, non-majors introductory biology courses. Mirroring the trend in K-12 education, the emphasis has shifted from a lecture-based course covering myriad topics towards a thematic approach on the biological underpinnings of current events (e.g., climate change) with integration of content literacy skills. By integrating evidence-based instructional practices at the university, we are modeling effective pedagogy and preparing students with a better foundational understanding of biology.

The adoption and implementation of the NGSS and CCSS are all clear mandates from governing bodies for the necessary changes in education; however, without adequate opportunities to support and train pre-service and in-service teachers these remain aspirational goals. Training teachers to assess students’ misconceptions, and using the
feedback to inform their instruction via best practices will continue to be an important precursor to preparing a scientifically literate populace. The FLGS courses continue to evolve to meet the needs of the changing educational landscape and play a critical role in modeling and preparing teachers to implement best practices aligned to state standards into their lessons.
Literature Cited


1. What are genes?
   a) Proteins
   b) Amino acids
   c) Segments of DNA
   d) Chromosomes
   e) Segments of RNA

The diagram below shows two different ways in which cells can divide.

2. Based on the diagrams shown above, which process shows the steps involved to create a gamete, such as a sperm
or an egg.

a) Diagram A shows the correct process because the offspring needs to have exactly the same DNA as their parents.

b) Diagram A shows the correct process because you need to maintain the correct number of chromosomes in order for a sperm to work properly.

c) Diagram B shows the correct process because you only have half the amount of DNA in the sperm as the rest of the cells in your body.

d) Diagram B shows the correct process because sperm are very small and will not fit as much information in it as a regular cell.

3. Which of the following human cells contains a gene that specifies eye color?

a) Cells in the eye.

b) Cells in the heart.

c) Gametes (sperm and egg).

d) Cells in the eye and gametes.

e) All of the above.
4. An inherited disease that affects women and not men is likely to be caused by:

a) a mutation in a gene on the X chromosome, which is a sex chromosome.

b) a mutation in a gene on a non-sex chromosome (autosome).

c) without additional information, either answer (a) or (b) is possible.

5. If you were to take a muscle cell from your heart and compare it to a skin cell taken from your arm, how would the DNA inside each cell compare?

a) The DNA is different because the cells are from different parts of the body.

b) The DNA is different because a muscle cell and skin cell have different jobs to do.

c) The DNA is the same because it is being taken from the
same organism.

d) The DNA is the same because all DNA is made up of the same four bases, A, T, G and C.

The table below shows all the possible outcomes of a cross between two flowers. Flower color is determined by one gene. If the dominant form (B) is present, then the flower will be purple. When B is absent, there is no color produced and the result is a white flower.

<table>
<thead>
<tr>
<th>Possible offspring from this cross</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bb</td>
</tr>
<tr>
<td>Bb</td>
</tr>
<tr>
<td>bb</td>
</tr>
</tbody>
</table>

6. The diagram above shows that purple flowers are more likely to occur in the offspring. Which is the likely explanation?

a) Since B is the dominant allele it will be passed onto offspring more readily.

b) Since bees are more attracted to purple flowers, the
flowers will need to become purple in order to reproduce.

c) A mutation occurred that causes the plants to produce more purple flowers.

d) The process is random. You cannot predict which form of the B gene will get passed from parent to offspring.

7. Cystic fibrosis in humans is caused by mutations in a single gene and is inherited as an autosomal (non-sex chromosome) recessive trait. A normal couple has two children. The first child has cystic fibrosis, and the second child is unaffected. What is the probability that the second child is a carrier (heterozygous) for the mutation that causes the disease?

a) 1/4
b) 1/2
c) 2/3
d) 3/4
e) 1
8. What is the primary function of DNA in a cell?
   a) It is a component of proteins.
   b) It is a structural feature of the cell.
   c) It is the blueprint for the operation of the cell.
   d) It is a major component of the fluid inside the cell.
   e) It makes the chromosomes move in a cell nucleus.

Below is a diagram where a mutation has occurred while the DNA is being replicated.

9. Suppose that a single DNA base change of an A to a T occurs and is copied during replication. Is this change necessarily a mutation?
   a) Yes, it is a change in the DNA sequence.
   b) Yes, if the base change occurs in a gamete (sperm or egg cell); otherwise no.
   c) Yes, if the base change occurs in the coding part of a gene; otherwise no.
d) Yes, if the base change occurs in the coding part of a gene and alters the amino acid sequence of a protein; otherwise no.

e) Yes, if the base change alters the appearance of the organism (phenotype); otherwise no.

10. A mutation occurs at a random location along a chromosome. The effect will likely:

a) Cause the DNA to work improperly and may result in a disease or disorder.

b) It depends upon the location of the mutation. In some spots there could be an effect and in others there would be no effect.

c) Have no effect on the individual.

d) There is not enough information to determine the effect.

Below is a diagram showing the process of how proteins are made:
11. You have identified a previously unknown human gene that appears to have a role in autism. It is similar enough in DNA sequence to a known mouse gene that you believe the two genes may be evolutionarily related. You determine and compare the DNA sequences, the predicted mRNA sequences, and the predicted amino acid sequences corresponding to the two genes. You would expect to find the greatest sequence similarity from comparisons of the two:

a) DNA sequences.

b) mRNA sequences.

c) amino acid sequences.

d) All three comparisons are likely to show the same degree of sequence similarity.
12. You are interested in studying a gene called CFTR because mutations in this gene in humans cause cystic fibrosis. You have made a line of mice that lack the mouse CFTR gene. These mice are unable to clear bacteria from their lungs, so they get lung disease. You put a normal human CFTR gene into some of these mice and discover that the mice with the human gene are able to clear bacteria from their lungs and no longer get lung disease. From this experiment, you can conclude that:

a) The DNA sequences of the mouse CFTR gene and human CFTR gene are identical.

b) The amino acid sequences of the mouse CFTR protein and the human CFTR protein are identical.

c) The mouse CFTR gene and human CFTR gene encode proteins that can serve a similar function.
d) Both answers b) and c) are true.

e) All of the above are true.

13. What is the primary function of mRNA in a cell?

a) It copies the DNA during cell division.
b) It transports nutrients into and out of the cell.
c) It is the template for the manufacturing of proteins.
d) It is the template for cell division.
e) It folds into cell membrane structures.

14. How does a cell make a specific protein every time it needs that protein?

a) It decodes all of the DNA in the cell’s nucleus.
b) It decodes only the sequence of DNA responsible for that protein made in that cell.
c) By splitting in half and creating more cells.
d) By copying the existing protein over and over.
e) By absorbing that protein from the digestive system.

15. Which of the following are made up of cells?

a) Human organs
b) Plants
c) Proteins
d) genes
e) a and b

Below is a diagram showing a protein being “folded”

16. When cells make different proteins, these proteins have different structures or shapes. Which of the following choices offers the MOST BASIC reason for proteins having different structures?

a) Each has a different sequence of amino acids.
b) Each has a different function from another.
c) Each are found in different places in the body in which they perform their “job”.
d) Each are found in the nucleus of the cell.
e) Each comes from a different food that we might eat.
17. The structures called mitochondria are the energy storehouses for the cell. Inside these structures, glucose is broken down to produce the energy required for the cell to survive. If we were to look more closely at a plant cell, would we find mitochondria?

a) No, plants are able to make their own energy through the process of photosynthesis.

b) Yes, plant cells are like animal cells in that they need to breakdown glucose to produce energy.

c) It depends on what part of the plant the cell was taken from. Some parts of the plants, like the roots, are not involved in energy production.
18. Each of the structures, or organelles, of the animal cell shown above is surrounded by a membrane. This membrane is necessary to:

a) Maintain a different environment on the inside of the organelle compared to the rest of the cell.

b) Control what goes in and out of the organelle.

c) Send and receive signals that allow it to respond to changes in the environment.

d) All of the above.

19. The oxygen that we breathe in, ultimately ends up:

a) Inside the tiny air sacs of our lungs.

b) Traveling through the bloodstream.

c) Reacting with carbon to create carbon dioxide.

d) Inside the mitochondria of our cells.

20. You eat a grape high in glucose content. How could a glucose molecule from the grape provide energy to move your little finger?

a) The glucose is digested into simpler molecules having more energy.

b) The glucose reacts to become ATP (Adenosine
Triphosphate).

c) The glucose is converted into energy.

d) The energy of the glucose is transferred to other molecules.

e) The energy of the glucose is transferred to $CO_2$ and $H_2O$.

Scientists have long believed that the 14 species of finches on the Galapagos Islands evolved from a single species of finch that migrated to these islands one to five million years ago (Lack, 1940), possibly from a group on the Caribbean Islands, as recent research has shown (Burns et al., 2002). Different species of finches live on the different islands that make up the Galapagos Islands. For example, the medium ground finch and the cactus finch live on one island. The large cactus finch lives on another island. One of the major changes in the finches is in their beak sizes and shapes as shown in this figure.
21. What would happen if a breeding pair of finches was placed on an island under ideal conditions with no predators and unlimited food so that all individuals survived? Given enough time,

a) the number of finches would stay small because birds only have enough babies to replace themselves.

b) the number of finches would double and then stay relatively stable.

c) the number of finches would increase dramatically.

d) the number of finches would grow slowly and then level off.

22. Finches on the Galapagos Islands require food to eat and water to drink.

a) When there is not enough food and water, some birds may be unable to get what they need to survive.
b) When food and water are in limited supply, the finches will find other food sources, so there is always enough.

c) When there is not enough food and water, the finches all eat and drink less so that all birds survive.

d) There is always plenty of food and water on the Galapagos Islands to meet the finches’ needs.

23. An island of finches has equal numbers of large-beaked and small-beaked finches. Would you expect to see any changes in the numbers of large- vs. small-beaked finches over time?
   a) Yes, because any changes in the environment will cause genetic mutations for beak size to meet the needs of the finches.
   b) Yes, because, over time, the numbers of small-beaked finches that survive and reproduce may be different from the numbers of large-beaked finches survive and reproduce.
   c) Yes, because the large-beaked birds are bigger, live longer, and lay bigger eggs.
   d) No, because group size may not change from generation to generation.
24. Depending on their beak size and shape, some finches get nectar from flowers, some eat grubs from bark, some eat small seeds, and some eat large nuts. Which statement best describes the interactions among the finches and the food supply?

a) Most of the finches on an island cooperate to find food and share what they find.

b) Many of the finches on an island fight with one another and the physically strongest ones win.

c) There is more than enough food to meet all the finches’ needs so they don’t need to compete for food.

d) Finches compete primarily with closely related finches that eat the same kinds of food, and some may die from lack of food.

25. How did the different beak types first arise in the Galapagos finches?

a) The changes in the finches’ beak size and shape occurred because of their need to be able to eat different kinds of food to survive.
b) Changes in the finches’ beaks occurred by chance, and when there was a good match between beak shape and available food, those birds had more babies.

c) The changes in the finches’ beaks occurred because the environment caused the desired changes in the finches’ DNA.

d) The finches’ beaks changed size and shape gradually with each generation, with some beaks getting larger and some getting smaller.

26. What caused the groups of birds with their different beak shapes and sizes to become several different species found on the different islands?

a) There were differences in the original group, and those finches with features that were best suited to the available food supply on their island reproduced most successfully.

b) All finches are essentially alike and there are not really fourteen different species.

c) Different foods are available on different islands and for that reason, individual finches on each island slowly developed the beaks they needed over time.
d) Different lines of finches developed different beak types because they needed them in order to obtain the available food.

This is a diagram of a terrarium. It can be useful in studying ecosystems, because it is a smaller version of what is occurring in larger habitats all over the world. The glass box keeps all of the gases trapped inside of the terrarium. Use this diagram to answer the following questions.
27. Plants need sunlight in order to grow. How does a plant use the sunlight to help it grow?
   a) The light energy is used as food for the plant.
   b) The light energy is absorbed by high energy molecules such as ATP.
   c) The light energy is used to power the process of photosynthesis.
   d) The light energy is converted into heat to keep the plants at a constant temperature.

28. Thinking about the gas exchange occurring in the terrarium above, you would find that:
   a) Plants create carbon dioxide so that animals can survive.
   b) Plants create oxygen so that animals can survive.
   c) Animals are not dependent on the plants because there is plenty of oxygen to allow them to live without any plants present.
   d) Plants and animals are equally dependent on one another to provide the necessary gases to survive.

29. As the plant grows, where does most of the new matter (leaves) come from?
a) From inside the plant parts that were originally inside the seed.

b) From the carbon dioxide and water that comes from the environment.

c) From the minerals in the soil that enter through the plant’s roots.

d) From sunlight that is captured by the tree’s leaves.

30. Which of the following organisms in the terrarium is least efficient at converting the energy it gets from eating or photosynthesis into energy it can use to live?

a) The plant, because most of the sunlight’s energy available to the plant is lost as heat.

b) The worms, because they use much of the food they eat is used to stay warm in the cold, dark environment underground and not to grow.

c) The snail, because it is only able to use a small amount of food it eats for energy to live.

d) The bacteria, because they are so small.

31. If an animal eats more food than its body can use right
away, what happens to the unused food?

a) All the unused food leaves the animal’s body as waste.

b) Some of the unused food is stored unchanged in the animal’s body for later use.

c) Some of the unused food is broken down and stored in the animal’s body for later use.

d) There is no unused food because all the food an animal eats is used immediately.

32. The bacteria in the terrarium are:

a) A secondary food source for the plants.

b) Serving a similar role as the worms.

c) Dangerous because they may cause the other organisms to get sick and die.

d) Having no impact since they are too small.