PROFESSIONAL DEVELOPMENT

AP® Biology

Visualizing Information

CURRICULUM MODULE

The College Board
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Introduction

All too often, we would like to pretend that the spheres of human creativity and inquiry are separated into neat domains, with clean dividing lines. Of course, we are kidding ourselves. The scientist and the artist are united in their pursuit of human understanding. While the tools and methodologies employed are often different, both fields — art and science — look to create new knowledge about the human experience and our place within the larger world.

This curriculum module provides a series of lessons that deal with the construction of visual models to help AP® Biology students understand the concepts within the curriculum framework. The usage of visual models in biological inquiry is a long tradition that predates the establishment of biology as a rigorous science (consider Leonardo da Vinci's *Vitruvian Man*, or even Cro-Magnon cave paintings). Modeling is intrinsic to the *AP Biology Curriculum Framework* as the foundation of Science Practice 1, indicating that it is a skill that students of all sciences are expected to be able to employ. It is not difficult to understand why this is the case. Through creating, analyzing, refining, and presenting models, the analytical, perceptual, and communication skills of the scientist are developed. And while models can take a variety of forms, visual models are particularly suited to the domains of biology. The use of visual models in the biological sciences is widespread. Open a textbook or consult a research paper, and you will be presented with a wide variety and diversity of visual models to help explain the concepts that are being discussed. These models range in form from simple graphs to complex diagrams, but fundamentally, they are connected in their usage of visual modes of communication to demonstrate concepts and facilitate understanding.

Unlike other curriculum modules, which may be typically organized around one particular unit of course content, this module is organized around one particular course concept that extends throughout its entirety. This module presents a series of art-based tools and procedures to help students visualize concepts from the AP Biology curriculum framework, then present that information in a visually compelling way. The lessons provide a variety of artistic experiences, and stress different aspects of the modeling process at different points. We have provided a range of visual modeling techniques borrowed from the practices of artists, designers, and scientists, and applied these varied techniques to different areas of the curriculum framework for different reasons. At the same time, all of the lessons are unified in their application of visual models to help students understand and communicate aspects of the curriculum framework. All of the lessons use the tools of artists and designers to help students refine their skills in visually modeling different types of understandings in a variety of ways.

An obvious question that might be raised relates to the necessity of the lessons we provide, particularly in a course that is notoriously short on time: What is useful in presenting these concepts in a visual way that makes using these lessons in the AP Biology course a better use of class time than doing something else?

Certainly, different instructors will have different perspectives on the answer to that question. As to time constraints, we have not provided any lesson in this module that occupies a particularly large amount of instructional time. But more importantly, the module's four lessons highlight curricular areas in which the use of visual models is more appropriate in aiding student understanding than using nonvisual techniques. The concepts covered in this module range from information presentation and graphic design to bioenergetic, and evolutionary processes at work in the biosphere. In each case, spending some time having students model these processes in a visual context provides students with an opportunity to develop their understanding that would be lacking in a nonvisual context. Additionally, this module can serve as a resource for students who are interested in the visual arts and the connections between art and biology.

Connections to the AP Biology Curriculum

In creating this module, we have provided four different lessons that enable students to use creative, visual processes and practices to engage in modeling scientific phenomena, and scientific practices. Modeling, and its uses, are firmly embedded in the AP Biology curriculum framework. Science Practice 1 states this explicitly, and makes plain the expectation that students will need to be able to create, describe, refine, use, and reexpress representations and models of natural phenomena and systems. The science practices are universal across all of the domains of scientific understanding that the AP program covers, and biology is certainly no exception.

We have provided activities that touch upon three of the four Big Ideas of the course. Lesson 2 asks students to model the effect of evolutionary forces upon a population of organisms by demonstrating how a particular mode of evolutionary change would affect the members of a population. In Lesson 1, students participate in the construction of a visual metaphor for the phenomenon of emergence within the context of contributing a section to a common work of art.

Along with these two activities, which approach concepts from different big ideas, we have also provided an activity that connects the importance of visual modeling to the laboratory experience. In Lesson 3, students create graphical representations of laboratory data sets, and use the principles of graphic design to refine and improve their representations.

To help frame the curriculum connections in this module, we have identified the most pertinent connections to the enduring understandings and essential knowledge components of the curriculum framework at the beginning of each lesson. While we have identified the major connections, we do not wish to suggest any of these activities has to be restricted to the curriculum connections we have provided. The thematic nature of the curriculum framework lends itself to cross-pollination, and as such, instructors should not be discouraged in pursuing connections between these activities and aspects of the curriculum framework that may not be initially apparent.

Connections to the AP Biology Exam

The AP Biology Exam requires students to understand and apply the content and concepts within the curriculum framework. In this way, each lesson addresses aspects of the framework, and by extension, content or concepts on which students will be assessed when they take the AP Exam. The focus of the exam on assessing conceptual understanding requires students have a strong foundation in modeling (as indicated by the focus on modeling in Science Practice 1), to enable them to develop their conceptual understanding. Given the nature of this particular curriculum module, we have tried to provide novel activities that allow instructors to incorporate the use of visual modeling when teaching some of the major concepts of the course.

A list of questions from the new sample exam that correlate to each of the lessons in the module is provided in Appendix E.

In focusing on evolution and bioenergetics, we are addressing two major content topics that are assessed on the AP Biology Exam every year. In presenting strategies for graphical presentation of laboratory data, we are addressing a science practice students are regularly expected to demonstrate on the AP Biology Exam. In investigating the phenomena of emergent properties in systems, we are giving students another way to think about a concept that comes up throughout the course, at all temporal and spatial levels of resolution. The development of student conceptual understanding and skills (via the science practices) in these areas is directly connected to the material and the application of the science practices that are assessed on the AP Biology Exam at the end of the year.

Instructional Plan

Like the laboratory component of the course, the activities we present are firmly rooted in inquiry-based practice. In these lessons, students are asking and answering their own questions, or developing their own approach to the tasks that are presented. Instructors should have the requisite skill set to foster student inquiry, a skill set instructors are already expected to be utilizing in the laboratory component of the course. As presented, the activities provide a range of possible student responses, without any single, obviously correct approach or answer. Instructors will need to facilitate student process, and help them to plan and implement their approach to these tasks. We have spotlighted a variety of junctions where instructors can elect to broaden or narrow the scope of student tasks as dictated by particular instructional circumstances.

Any instructor who feels the need to gain some background understanding and fluency with the process of inquiry and questioning to facilitate learning is encouraged to consult the new 2012 AP Biology lab manual (*AP Biology Investigative Labs: An Inquiry-Based Approach*). The introductory material and appendixes have a large amount of discussion and supplementary resources devoted to these questions.

Another major area of knowledge instructors will need to bring to the table relates to the artistic/creative aspects of these lessons. We do not expect instructors to possess the same level of artistic talent as members of their schools' art departments. Our goal is not to provide lessons that challenge the instructor with the level or amount of artistic material, but rather to spotlight four areas of the course where the incorporation of visual modeling can play a useful pedagogical role. In each of the lessons, we have provided instructor notes regarding the creative processes that are employed, along with options for broadening or narrowing the scope of these processes for instructional/student comfort level. We have also provided a variety of relevant resources for these activities in the resource section of the module.

Assessments

Each lesson provides detailed information on formative and summative approaches to assessment within the structure of the lesson. Generally speaking, we propose that the majority of summative assessment will take place through questioning and monitoring of student progress and interaction. Additionally, students are generating artifacts as evidence of understanding in each of these lessons, which include the visual models that they create, along with a variety of written responses to instructional prompts, as well as presentations of their work to instructors and peers. These artifacts are similarly informative of student conceptions from a formative standpoint, and the completion of these lesson requirements may well serve instructional purposes in a summative capacity.

The curriculum framework is informative in guiding instructor assessment of student work. How well does the work students accomplish during these lessons demonstrate the particular learning objectives we have identified for each lesson? How well does the work demonstrate student ability in applying particular science practices? Keeping these questions in mind should help instructors to frame their formative and summative assessments of student work.

We would stress one point: Students should not be assessed on the artistic quality of the work that they create. The assessment of "creativity" is notoriously difficult, and we do not expect that students will approach these activities with a uniform artistic ability. Rather, assessment should reflect the degree of success students achieve in visually communicating a given concept utilizing the artistic processes described. Peer assessment of one another's work could be useful in this manner. Student artwork should convey information in a manner relatable to any given viewer.

Prerequisite Knowledge

Lesson 2 requires specific foundational knowledge related to two of the big ideas of the AP Biology curriculum framework. Students need to understand certain foundational aspects of evolutionary biology and mechanisms of evolutionary change in populations. We do not expect instructors will utilize either of these activities prior to covering this material in the course of instruction.

The other two lessons require much less content knowledge to be utilized with students. Lesson 1 requires students to construct a collaborative drawing as a visual model of a system, demonstrating the concept of emergence. Lesson 3 has students utilize the principles and practices of graphic design to construct infographics (representations of information, data, or knowledge that present complex information in a clear, visual manner) related to their laboratory experiences.

Both of these lessons can be implemented at various points in the instructional sequence, regardless of whether students have been exposed to particular content knowledge or skills prior to the course. We do not suggest there is any major advantage to using these activities as either introductions to the concepts with which they deal, or as ways in which instructors can broaden student understanding of the material that they cover.

From an artistic standpoint, it is assumed students have a very basic understanding of certain elementary visual concepts: observational drawing, collage, and the graphic elements utilized in infographics. Any other requisite artistic concepts will be addressed individually within the lessons.

Instructional Time and Strategies

Within each of the activities, we have tried to be conscious of the ever-present time considerations that accompany the typical AP Biology course. We have not provided any lesson that occupies an undue or extravagant amount of instructional time. Here is a rough estimate of the time required for each lesson (based on a period length of 40–50 minutes).

Lesson 1: Collaborative Drawing Illustrating the Concept of Emergent Properties

- **Introduction and Segment Creation:** One Period (with possible homework time for segment creation)
- **Collaborative Drawing Construction and Reflection:** One Period

Lesson 2: Modeling Evolution

- **Introduction:** One Period
- **Model Creation:** Two Periods (or comparable time out of class)
- **Presenting:** One Period

Lesson 3: Visualizing Data

- **Introduction:** Half of a Period
- **Graph Construction:** One Period
- **Design Conversation and Revision:** One Period

In the resources section, we have provided Web links to short video clips for selected lessons that might encourage student conceptual understanding for those lessons prior to beginning these activities.

In terms of when, exactly, instructors should utilize these lessons in their course sequence, we suggest that it depends upon the curricular sequence of a particular course. These are not sequential lessons. We have tried to structure the lessons with a modularity that will allow instructors to bring the lessons into their class when their particular instructional sequence dictates a lesson would be appropriate. Lesson 1 has been created to be taught during the instructional sequence on evolution. Lesson 2 has been created to be taught either during the instructional sequence on bioenergetics, or ecology. Lesson 3 is more flexible in its implementation. Instructors may find utility in using it early in the year, or waiting until particular aspects of the course are approached.

Lesson 1: Collaborative Drawing Illustrating the Concept of Emergent Properties

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Essential Questions

- How does complexity emerge from the interactions of the parts of a system?
- How does structure relate to function? If a component of a system changes, how does this change affect the structure and function of the system?

Lesson Summary

This drawing lesson is a collaborative, part-to-whole activity that is designed to introduce students visually to the concept of emergent properties.

Connections to the AP Biology Curriculum Framework

This lesson directly addresses the following understandings and learning objectives of the AP Biology curriculum framework:

Big Idea 4: Biological systems interact, and these systems and their interactions possess complex properties.

- **Enduring Understanding 4.A:** Interactions within biological systems lead to complex properties.
- **Essential Knowledge 4.A.4:** Organisms exhibit complex properties due to interactions between their constituent parts.
- **Learning Objective 4.8:** The student is able to evaluate scientific questions concerning organisms that exhibit complex properties due to the interaction of their constituent parts. [See **SP 3.3**]

- **Learning Objective 4.9:** The student is able to predict the effects of a change in a component(s) of a biological system on the functionality of an organism(s). [See **SP 6.4**]
- **Learning Objective 4.10:** The student is able to refine representations and models to illustrate biocomplexity due to interactions of the constituent parts. [See **SP 1.3**]

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

- **SP 1.3:** The student can refine representations and models of natural or man-made phenomena and systems in the domain.

Science Practice 3: The student can engage in scientific questioning to extend thinking or to guide investigations within the context of the AP course.

- **SP 3.3:** The student can evaluate scientific questions.

Science Practice 6: The student can work with scientific explanations and theories.

- **SP 6.4:** The student can make claims and predictions about natural phenomena based on scientific theories and models.

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

- **SP 7.2:** The student can connect concepts in and across domain(s) to generalize or extrapolate in and/or across enduring understandings and/or big ideas.

Student Learning Outcomes

As a result of this lesson, students should be able to:

- develop their understanding of the concept of emergent properties through the visual metaphor that they create in constructing a collaborative image;
- provide an explanation for how complexity emerges from the interactions of the parts of their visual system;
- demonstrate a sufficient level of observation to be able to represent their part of the whole image;
- demonstrate an understanding of basic drawing techniques, including the ability to render a range of values without the benefit of recognizable subject matter to guide them; and
- develop their observation skills, and recognize the importance of careful observation in both artistic and scientific settings.

Prerequisite Knowledge

To effectively engage with this activity, students should be familiar with the major concepts of systems theory. Simply put, the whole of a system has novel properties that the parts of that system do not. These properties emerge from the interactions of the components of the system. Mathematically, as the number of parts in a system increases linearly, the number of total interactions among those parts increases exponentially. We do not expect that students will have a particularly well-developed sense of these concepts (indeed, there are quite a few graduate students in the sciences who do not have a particularly well-developed understanding of these concepts), but we do assume that these concepts are not completely foreign to students as they begin this activity. If required, instructors should take some time to address these aspects of systems theory prior to beginning this activity. Instructors can find utility in using examples of systems from both the biological and the nonbiological world. (An obvious example would be the school system of which the students are part.)

Common Student Misconceptions

The concept of emergent properties is a fundamental tenet of systems-thinking, and our understanding of biological systems. It is also a very difficult concept for students to grasp. Students study biology from different levels of biological organization. From molecules to the biosphere, there are common characteristics that define and give perspective to life; however, as the scale is increased from atoms to molecules or organs to organ systems, properties emerge and more can be accomplished in the higher level of organization. The reductionist nature of science curricula often works to obscure system dynamics. Students often study the components of living systems separately, in chapters in a text that intentionally put the details of cells, tissues, or ecosystems into a concise format that gives focus. However, to understand living systems, it is important for students to make connections between scales and to understand the overall organization of the components of biological systems and the emergent properties that are evident as the scale is increased. If any component is changed either by natural occurrences or by environment catastrophes, molecules, cells, organisms, populations, or ecosystems could be different. Moreover, components combine not just to form wholes, but the whole then has qualities that the individual components do not.

Teacher Learning Outcomes

At the conclusion of this lesson, teachers should expect that students will be able to relate the concept of emergence to the visual constructive experience of this lesson. In this way, instructors are able to provide students with an example of emergence from a system that is outside the typical systems under consideration in AP Biology, demonstrating the universality of systems concepts across domains (Science Practice 7). Typically, this is not an easy science practice for which to provide visual examples. This module will also provide instructors with an opportunity to incorporate more visually oriented strategies into their classroom practice.

Materials or Resources Needed

Materials:

- White sticky notes, unlined index cards, or drawing paper
- Pencils: No. 2B (preferred). These drawing pencils have slightly softer, darker leads, but a regular No.2 (HB) pencil can be used as well.
- Erasers:
  - White plastic eraser
  - Kneaded eraser

  The pencils and erasers are both readily available at art and office supply stores or possibly at the school's art room.
- Poster or mat board large enough to mount all of the finished squares on a grid

Activity: The Parts of the Whole

In Part 1 of the activity, utilizing a grid system, students are given small squares of the image to draw as accurately as possible on a larger square. Each individual square taken out of context is viewed as a series of abstract shapes and textures that are closely observed and recorded by the students.

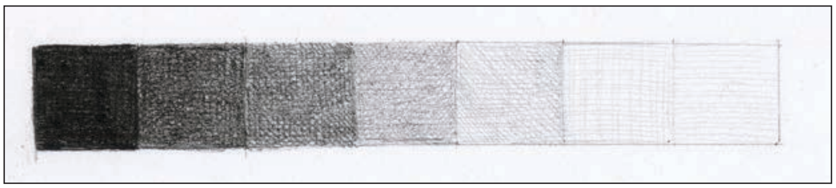
Prior to the activity:

1. Instructors should select an image that will serve as the basis for student drawings. This image will be cut down into squares, so teachers may opt to use a poster, or choose an image online that is high-res enough to print on a larger scale. Images of people, animals, plants, or even bacteria can all work equally well. Regardless of the subject matter, it will work best if this image is black and white.
2. Teachers should use the back of the image to divide it into a grid, cut the images down into squares, and number the squares sequentially. Any numbers that are ambiguous such as 9 and 6 should be underlined. They can then draw an arrow indicating the top of the image to clarify orientation. To keep the subject matter of the picture hidden from the class, the picture should be cut into squares small enough so the parts cannot be easily identified before the students have a chance to see the image as a whole. The size of the squares depends on the size of the print that is being used, but there should be at least one square for each student participating in this activity.

3. Students will need white paper to draw on for this activity, which will also be cut into squares. This can be approached in a number of ways: Teachers can cut squares of drawing or sketch paper, use white sticky notes, or cut unlined index cards down into squares. Ideally the scale of the drawing will be bigger than the original image. For example, if the poster squares are 2 x 2 inches, the squares of drawing paper could be 3 x 3 inches or larger.

Session 1:

1. The instructor should explain to students that they will be doing a short drawing activity as a part of the day's discussion. If students are uncomfortable with the idea of drawing, it may be useful for the instructor to have them take a few minutes to create a simple value scale by replicating the one below. Students should practice replicating this scale by reproducing each of the shades from dark to midtone to light (which will be the white of the paper) with their HB or 2B pencils.



2. The teacher should introduce the drawing activity:
   Students will select one (or more) of the black-and-white image squares and an equal number of pieces of white drawing paper, along with a pencil and eraser. *Their task is to use their pencil and eraser as tools to replicate the black-and-white image as faithfully as possible on their white square.*
   - A useful sequence for working might be:
     - Lightly draw the main shapes, using only lines.
     - Add the middle-tone grays, and then the darkest tones, using your value scale for reference.
     - Using your eraser, add in the lightest highlights.
   - Instructors should remind students that their value scales can be useful tools in measuring whether their light and dark areas are accurate. In addition to their pencils, their erasers can also work as drawing tools: They might choose to shade in an area and erase out the lighter areas.
3. Instructors should establish a timeline for completion. This will vary according to class size, as smaller classes may require each student to complete several squares. Depending on instructional circumstances, students may work to complete their squares in class or at home.
4. Once students have completed their squares, instructors should discuss the process of replicating the photographs with the students. What was interesting about this process? What was difficult? Why do you think you were asked to do this? Did you develop any strategies or techniques for yourself as you worked?

5. Instructors should label backs of drawings with number on back of square and use an arrow to indicate which side of the drawing is the top.

Part 2: Modeling Emergence

In Part 2 of the activity, all of the students' drawings are combined on a grid to create one large image.

Prior to the activity:

If teachers would like to keep the final class image for more than a temporary discussion, they should prepare a backdrop on which to affix the drawn images. This may be a large piece of mat board or foam core board. For greater accuracy in the assembly of the drawings, teachers may also draw a grid on the board that matches the scale of the drawings, and number the squares from lowest to highest from right to left. (Alternatively, a group of students could be asked to prepare the grid.)

Session 2:

- The teacher may invite each student to attach his/her drawing to the poster board in the appropriate space on the grid. As more and more drawings are added, the image will emerge.

Formative Assessment

The major formative assessment opportunity arises after students have made their contribution to the group construction, and the constructed image emerges from student sections. After the full drawing is assembled, instructors can use the following prompts to assess student's formative conceptions of emergence as demonstrated in the activity. This assessment is based on class discussion or could be a written summary after the general class discussion.

- How is the whole greater than the sum of its parts?
- What properties emerged with the completion of the grid?
- What part did your section play in the whole picture? What understanding would be missing if your section was not added or was missing?
- How did the process of making the image from components model a biological system?

In analyzing student responses to these questions, instructors should expect students to provide cogent answers, with evidence from the constructed work used to support their responses. If instructors find students are not providing cogent, supported answers, instructors will need to remediate. This can take many forms, but an approach instructors may find useful is to reference different systems from other areas of student understanding and apply the same questioning template to elucidate the understanding that all systems possess universal properties.

Another avenue instructors should consider is to have students write scientific questions that come to mind as they work through this activity. Learning Objective 4.8 requires that students evaluate scientific questions. To that end, students could be expected to share their questions with their peers to engage in a process of peer review as an evaluation mode of the scientific questions students have developed. Students could easily apply the model they have investigated in this lesson to other phenomena localized more in the biological domain. If instructors do have students engage in this approach, students could be encouraged to use the questions they have developed to frame hypotheses or describe the design of possible experiments to address their questions. Instructors could facilitate the development of student questions by providing students with supplementary materials, such as incomplete grids, and then asking students what additional information they could infer or need to answer questions. They could also be asked whether any information they have been provided could be left out to address the answers to their questions. All of these approaches could be utilized in follow-up discussion to consider how each piece functions to affect the totality of student understanding.

As a visual extension of this class discussion, students may be interested in looking at the work of artist Chuck Close, who creates large-scale paintings that from a close distance resemble grids of abstract lines and shapes, but from farther away are strikingly realistic portraits. Images of Close's portraits are readily available online, and several books on his work and his life have also been published in recent years. Instructors may invite students to view samples of his work either as a class or in smaller groups, and use the following questions as conversation prompts:

- How is Close's working process similar to or different from yours?
- What are the similarities and differences in the overall effect produced in his work versus the class drawing?

Samples of Student Work

Below are photos taken as students assembled their collaborative drawing:

Reflection

At the risk of repeating ourselves, the point of this activity is to demonstrate that all systems possess a set of universal features, including emergence, combinatorial complexity, and interdependence of elements. To this end, it is important that instructors reference the understandings of this lesson throughout the course, as other systems are encountered and discussed. The nature of the curriculum is such that multiple systems across multiple domains of space and time will be encountered and reencountered. Instructors should look to use the concepts developed in this activity as a template for analyzing the systems that will be considered during the rest of the course. Additionally, properties of systems will be evident throughout the course that the particular visual system in this lesson does not particularly demonstrate (e.g., feedback). If students grasped the concepts of this lesson to the satisfaction of instructors, instructors may consider expanding this activity to investigate some of these additional phenomena.

There is no particular difference in the approach instructors should take if students struggled, though instructors will be well served by stressing the applicability of these concepts throughout the course to aid in student comprehension. Similarly, an opportunity arises to further develop understanding if students struggle. The dissonance and resolution of the activity can demonstrate that learning is not always (or even often) easy, and that it is okay to be frustrated while working through a particular process. Additionally, expanding the feature set of the system under investigation, as described in the preceding paragraph, is probably not the best course of action to take.

Lesson 2: Modeling Evolution

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Essential Questions

- How do populations of organisms evolve?
- How does evolution lead to change over time?
- How can we represent the process of evolution in a population?

Lesson Summary

In this lesson, students are asked to consider the ways that evolution can lead to changes in the characters seen in a population of organisms. Once they have decided on a mode of evolution they are interested in pursuing for the activity, students will be constructing a visual representation to show how the mode of evolution they are considering might affect the traits seen in a population of organisms. Rather than model the entire population, students will be representing a "typical" individual from the pre-evolved population and a "typical" individual from the post-evolved population, presenting a visual hypothesis for the changes that their selected mode of evolution will have on their sample. Students will need to consider their mode of evolution and how they can represent a way the evolutionary process has resulted in changes to the population via this single individual "case study." Along with this visual model, students will be asked to compose a brief written explanation of their model and how it represents the mode of evolution they are trying to show.

Connections to the AP Biology Curriculum Framework

This lesson directly addresses the following understandings and learning objectives of the *AP Biology Curriculum Framework*:

Big Idea 1: The process of evolution drives the diversity and unity of life.

- **Enduring Understanding 1.A:** Change in the genetic makeup of a population over time is evolution.

- **Essential Knowledge 1.A.1:** Natural selection is a major mechanism of evolution.
- **Essential Knowledge 1.A.2:** Natural selection acts on phenotypic variations in populations.
- **Essential Knowledge 1.A.3:** Evolutionary change is also driven by random processes.
- **Enduring Understanding 1.C:** Life continues to evolve within a changing environment.
  * **Essential Knowledge 1.C.3:** Populations of organisms continue to evolve.
- **Learning Objective 1.5:** The student is able to connect evolutionary changes in a population over time to a change in the environment. [See **SP 7.1**]
- **Learning Objective 1.8:** The student is able to make predictions about the effects of genetic drift, migration, and artificial selection on the genetic makeup of a population. [See **SP 6.4**]
- **Learning Objective 1.25:** The student is able to describe a model that represents evolution within a population. [See **SP 1.2**]

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

* **SP 1.2:** The student can describe representations and models of natural or man-made phenomena and systems in the domain.

Science Practice 6: The student can work with scientific explanations and theories.

* **SP 6.4:** The student can make claims and predictions about natural phenomena based on scientific theories and models.

Science Practice 7: The student is able to connect and relate knowledge across various scales, concepts, and representations in and across domains.

* **SP 7.1:** The student can connect phenomena and models across spatial and temporal scales.

Student Learning Outcomes

As a result of this lesson, students should be able to:

- explain how evolution can cause changes to the structure of a population;
- explain how evolution can cause changes to the traits of an individual in an evolving population;
- model the effects of different evolutionary forces on the structure of a population;

- compare the effects of different evolutionary forces on the structure of a population;
- justify the choices made when deciding how to model evolution within a population;
- create a visual representation of a hypothetical evolutionary adaptation that is firmly based in scientific theory; and
- make careful and deliberate visual decisions in developing their creative solution.

Prerequisite Knowledge

This lesson can be utilized during the normal sequence of an AP Biology unit on evolution, at some point after students have been introduced to the concept of evolution, and how evolutionary forces drive the changes in populations that are seen when looking at the biosphere. It is assumed that students will have some understanding of the nature of variation, its causes, and the interplay between variation and evolution. Students should be familiar with the major modes of evolutionary change: Natural selection, genetic drift, gene flow, and sexual selection, being, perhaps, the four most obvious and typically taught. Students should similarly have an understanding of how selection can affect the distribution of variants in a population (e.g., the classical patterns of stabilizing, disruptive, and directional selection), and have been exposed to real-world examples of evolution in action, which they can elucidate when explaining evolutionary phenomena.

Students do not need to have an advanced understanding of these topics, but the activity, as it is presented, assumes a certain baseline of student familiarity with the major threads of the topic, and the expectation is that students will use the experience of this activity to broaden their conception of evolutionary change. If instructors are considering using this lesson with students who have deficits in this background knowledge, we suggest they wait until they have addressed such deficits over the course of their instruction before utilizing the activity as it is presented. Certainly, instructors have the option to tailor the activity to meet the needs of their particular student population, as well.

Common Student Misconceptions

As most instructors will be aware, student misconceptions about evolution are widespread. Students persist in viewing evolution through a Lamarckian lens, or inferring directionality and teleology in the evolutionary process. It is important instructors remain alert to student demonstration of this mode of thought and work to correct it as it arises. *This is particularly germane to this lesson, as students will be modeling a mode of evolution in a hypothetical population, and can easily fall into mistakes in thinking about the topic if instructors are not vigilant.*

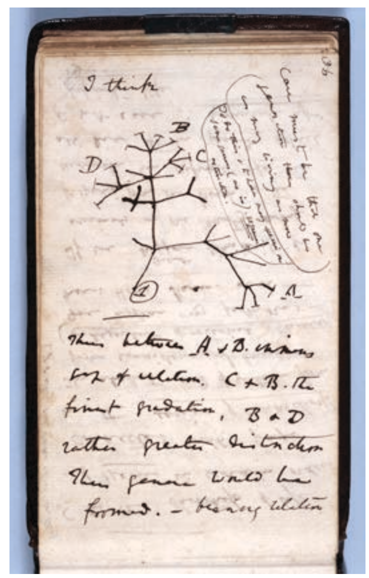
Another major area of misconceptions students have about evolution that may be demonstrated in this lesson are issues related to the nature of fitness. At the AP level, particularly early on in discussions of evolution, students may still relate fitness to “strength” or “dominance.” Students may demonstrate this thought process when modeling the effects of evolution on their hypothetical population.

In those cases, instructors should work to get students to vocalize the reasoning behind their choices and help them to reexamine their notions of what makes a particular organism well adapted in a particular environment.

Teacher Learning Outcomes

This activity provides instructors with an opportunity to address concepts and learning objectives from Big Idea 1 of the curriculum framework. Students are provided with an opportunity to model the effect of a mode of evolution on the structure of a population and to provide a scientifically justifiable hypothesis to explain how their particular mode has led to the specific changes in traits seen in the population. In this manner, instructors are presented with an opportunity to formatively assess student conceptions of how evolution works in populations. Given the widespread nature of student misconceptions related to evolutionary processes, this activity can be viewed as yet another resource in an instructor's toolkit to address and rectify these issues.

The process of visually representing information has tremendous value for students as science learners. Visual representations of models and processes are commonplace in scientific papers. (One could point to Darwin's own "I think" tree diagram in his original notebooks as perhaps the first major visual representation of modern evolutionary theory.) While the activity in which students will engage will certainly be more imaginative than many contemporary examples of visual modeling in scientific sources, this activity provides instructors with a chance to stress the utility of visual representation in understanding and presenting concepts.



Materials or Resources Needed

Materials and art supplies may vary according to the parameters set by the teacher for this lesson, but may include:

- Pencils
- Erasers
- Colored pencils/markers
- Scissors
- Glue sticks
- A variety of types and colors of paper
- Light box
- Optional: digital-imaging software (e.g., Photoshop, GIMP)
- Reference images for the populations being studied, or Internet access for students to locate these examples themselves

Activity: Modeling the Evolutionary Process

Part 1: Introduction

To begin this activity, the instructor should choose a real-world example of a visual model of evolution in action (e.g., peppered moths, rock pocket mice, antibiotic-resistant bacteria). Images from the course textbook will provide instructors with a variety of examples from which to choose. We have also provided a few resources dealing with some of these examples in the appendixes to the module. Showing the "before" and "after" images, the teacher should prompt students with a few discussion questions:

- What is being presented/hypothesized in this visual representation?
- How can you tell?
- How is presenting this information visually different from only verbally describing it?
- Are there any strengths or weaknesses in the visual representation of the process being shown?

Natural selection is a major force of evolutionary change. However, it is not the only source. The instructor should explain to students that in this activity, they will consider the different forces of evolution and how they can lead to changes in the characteristics that are seen in a population of organisms. They will construct a visual model, in the form of before-and-after drawings, collages, or altered photographs, of an individual from a selected population. The first image will represent the subject prior to that population experiencing an evolutionary pressure, and the second will be a model of an individual from the same population, following the effect of the chosen evolutionary pressure.

It is crucial that instructors stress that while this is a hypothetical modeling process, it is not a "make believe" or otherwise fantastical circumstance. Instructors need to make sure students are clear in the scientific rigor of their explanations as to why they made their models the way that they did. Students will need to provide a justification (a claim supported by evidence and reasoning compatible with modern evolutionary theory) as to why the population has evolved the way it has, and will need to provide descriptions of the selective force that worked to drive the evolution of their population in the direction that they represented. Instructors should also strongly caution students to avoid any Lamarckian thinking or the proposal of so-called "just-so" stories (the notion that organisms evolve in particular ways in order to be able to do particular things), and work to rectify these sorts of mistakes in thinking as they develop over the course of this activity.

Note: The following planning discussions have a companion student handout/planning sheet in Appendix A.

Choosing a Population to Study

There are a variety of decisions instructors can make when determining how restricted or expansive to make the criteria for the population students will be modeling. Is it a real-world population or a hypothetical one? Will all students be modeling evolution at work in the same population, or can they model the process in different populations? We take no position as to which criteria are preferable, though we are of the opinion that taking a current organism and working backward to represent the ancestral condition is probably the least creative mode instructors could employ.

Choosing a Mode of Evolution

Typically, we discuss four major modes of evolution (though the dividing lines between these modes are merely conveniences and the instructors may not have been taught about each of the following modes as a distinct evolutionary process).

- Natural selection: Differential reproductive success due to the adaptations that organisms possess that enable them to survive in the environment.
- Genetic drift: Nonselective changes in a population due to random events in the environment.
- Gene flow: Changes in a population due to the immigration and emigration of individuals to and from that population.
- Sexual selection: The development and persistence of traits in a population that increase the reproductive success of individuals. Not necessarily adaptive with respect to the long-term survival of individuals who possess those traits.

Each mode is unique in terms of the source of the evolutionary pressure and the effect the mode has upon the population.

While students may decide to model natural selection, instructors should encourage them to think about the other modes of evolution and, perhaps, model their effects instead. A bit of unsolicited advice: Students should choose the mode of evolution of which they have the least understanding, as this activity will help them to develop that understanding.

Part 2: Modeling

At this point, students are transitioning from the planning to the execution of their model. They will take their notes from the “pre” and “post” columns of their planning worksheets (see Appendix A) and translate those ideas into a visual presentation. The choices they make must be representative of the mode of evolution they are investigating, and students must be able to justify their decisions.

To aid their work, students should gather visual references of their subjects from the Internet. Ideally, this should include multiple views, close-ups, and interior and exterior shots, in order to give the greatest amount of information possible.

Materials are open, but approaches that will be nonintimidating for most students and that lend themselves particularly well to this lesson are:

- **Drawing:** Students can draw their model with pencils, colored pencils, or markers. Students can either prepare "before" and "after" drawings of their population, or they can use a photograph to stand in for the first image and draw only the second.

- **Collage:** In this case, the model would be created by building their images out of cut or torn paper. Students can draw further details on the model later, resulting in a mixed-media creation. In taking this approach, students could either create two separate images, or they can collage over the top of a drawing or photograph that would serve as the "before" record.
- **Digital techniques:** Students can create and/or alter an image of their selected population using Photoshop or other software for photo manipulation.

Materials can be as simple or as elaborate as the instructor prefers. This lesson offers a great opportunity for collaboration with the school's art teacher, if schedules allow, and he/she may have more materials suggestions.

Any approach they choose will involve the creation of planning sketches before moving onto their final works. The second part of the handout for this activity in the appendix offers questions and prompts to guide students through this portion.

The planning sheet in Appendix A will assist students in deciding how to structure their before and after sequence. The finished work should clearly highlight the adaptations selected by the students. They may opt to label their diagrams or choose other ways to clearly visually highlight the adaptation. This could be done in the manner of medical illustrations. If the adaptation is internal, students could present an interior/exterior view. Students must decide how they visually highlight the adaptation. Color? Will certain features be blown up in detail shots? Students must be able to justify how these adaptations would aid in evolution.

Conclusion

The activity concludes with students showing one another their representations. The instructor should ask students whether they can determine the represented mode of evolution in their peers' work, and encourage them to converse with one another. Following the dialogue, students may write about their models: the conception, process, and execution. They should frame explanations of how their models address the particular mode of evolution.

Students can also write about the work of their peers and relate it to their own work. How have other students modeled other modes of evolution? What was the thought process employed? How does each model compare? If multiple students modeled the same evolutionary mode, what were the similarities and differences?

The forum and style for student presentations is left to the instructor's discretion. Instructors may wish to have students present to the whole group in a traditional style, or have students exchange their representations in a more informal, conversational setting. Regardless of preference, it is important students have an opportunity to explain their choices, both in terms of biological basis (the evolutionary choices and changes), and on an artistic level (the way they represented their choices) and why they have made them, as it provides a major opportunity for instructors to gauge the quality of student conceptions related to evolutionary processes.

The teacher should instruct students to compose a brief response about their models, making sure to address the following aspects of the process:

- What evolutionary process did you model?
- How did you model it?
- Why did you choose to represent your evolutionary process in the way that you did? Explain why you have made your choices.
- Describe the circumstances that have led to the evolutionary process you have represented.
- Is your mode of evolution selective? If so, what is the source of the selective pressure you have represented?
- Is your mode of evolution random? If so, how did the random nature of the process affect the members of your population?
- All modes of evolution require variation to be present in the ancestral population. What is the source of the variation that led to the evolution you have represented?

Formative Assessment

This lesson provides two major opportunities for formative assessment: during students' planning of their projects and in their presentation of them. In the first, instructors should engage students in questioning about the choices they are making and have made in deciding which evolutionary process to model and why. The questions in the planning sheet in the appendix will be useful here. Instructors should expect students to provide cogent, well-considered answers to questions about their organism and the changes they are showing. In particular, instructors should expect that students will be able to explain why they are planning to change their organism in the manner they have indicated and that the explanation does not fall into the cognitive traps discussed in the misconception section of this lesson. If student explanations are not well formed or demonstrate aspects of Lamarckian, teleological, or otherwise mistaken thinking, instructors should work with students to help them realize the mistakes in their logic.

Given the widespread nature of student misconceptions about evolutionary processes, some reinforcement of evolutionary theory is probably warranted. Also, instructors should make sure students understand that even though "typical" individual organisms are modeled in this activity, it is the population of a species that is the functional unit for evolution.

The presentation aspect of the lesson provides the second major area for formative assessment of student conceptions. *Instructors need to consider reinforcing and possibly reteaching concepts if students are unable to explain why they have modeled their population in the way that they have, if they are unable to provide answers as to the nature of the selection mode they modeled, the source of any selective pressure, and how that pressure has resulted in the changes they have shown.* For example, a student may decide to model genetic drift in a population by showing how coat color has changed over a time interval. She may justify the change that she has illustrated by explaining how a random natural disaster resulted in the death of 90 percent of the original population. She may explain that the descendent population has a different frequency of coat colors because the survivors had a different frequency of colors than the original population as a whole did. This is a well-developed, justified explanation that shows a clear understanding of the mode of evolutionary change that the student chose. If the student were to instead justify her choice of genetic drift by stating that the coat colors that are shown in the survivor population helped the animals to survive the event that caused the other members of the population to die off, this would represent a less developed answer, as the student is conflating two different modes of evolution (supplying an explanation more consistent with natural selection than genetic drift). If a student cannot offer a cohesive explanation, this is the least developed type of response. Depending on the scope and scale of this activity, instructors may consider using a rubric to aide them in evaluating student work.

Reflection

In the main, we would expect most instructors will choose to utilize this activity within the context of their evolution unit, and as such, the most common next step instructors will take will be to move on with the instructional sequence, or possibly to review some of the concepts from the activity, if formative assessment suggests such remediation is required.

That said, there are several avenues instructors could take to broaden the scope of the activity if they are so inclined. Below are selections of possible expansions to the activity as presented.

- Mathematical modeling of the evolution of the hypothetical population. Graphical representation of changes in allele frequencies, or the distribution of traits in the population over the time frame represented.
- Consideration of how other modes of evolution would affect the distribution of the characteristic/trait modeled, with the possibility of further visual modeling.
- Analogy construction linking the hypothetical situation that students have modeled to a similar, real-world evolutionary circumstance, with discussion of major similarities and differences.

Lesson 3: Visualizing Data

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Essential Questions

The following essential questions are considered when framing this lesson.

- Why is the visual representation of data useful for scientific examinations and explanations?
- How can the principles of graphic design be used to help create scientifically rigorous and aesthetically effective representations of data?
- What are the major aspects of a good visual representation of data?

Instructors should remember the specific circumstances of their student population when deciding how to frame these questions for their students.

Lesson Summary

In this lesson, students explore possibilities for using both traditional and nontraditional information graphics to represent data sets and convey information about lab findings.

Connections to the AP Biology Curriculum Framework

This lesson directly addresses the following science practices in the AP Biology curriculum framework:

Science Practice 1: The student can use representations and models to communicate scientific phenomena and solve scientific problems.

- **SP 1.1:** The student can create representations and models of natural or man-made phenomena and systems in the domain.
- **SP 1.2:** The student can describe representations and models of natural or man-made phenomena and systems in the domain.

- **SP 1.3:** The student can refine representations and models of natural or man-made phenomena and systems in the domain.

Science Practice 2: The student can use mathematics appropriately.

- **SP 2.1:** The student can justify the selection of a mathematical routine to solve problems.
- **SP 2.2:** The student can apply mathematical routines to quantities that describe natural phenomena.

Science Practice 5: The student can perform data analysis and evaluation of evidence.

- **SP 5.1:** The student can analyze data to identify patterns or relationships.
- **SP 5.2:** The student can refine observations and measurements based on data analysis.
- **SP 5.3:** The student can evaluate the evidence provided by data sets in relation to a particular scientific question.

This lesson is designed to be iterative, with components that can be used multiple times through the year. Certainly, if instructors are not interested in such an approach, the lesson could easily be used at any point in the year when students are being asked to represent data graphically.

Instructors are encouraged to consult the new publication, *AP Biology Quantitative Skills: A Guide for Teachers*, available on the College Board's website, for detailed supplementary information about the construction of line graphs and the application of mathematical routines to data sets.

Student Learning Outcomes

As a result of this lesson, students should be able to:

- create visually appealing and scientifically sound representations of data;
- be able to analyze graphical representations of data, and refine those representations to improve their construction; and
- justify the design choices they have made when constructing graphs on an aesthetic and scientific basis.

Prerequisite Knowledge

Given its focus on lab skills, this lesson does not require any major content knowledge from the curriculum framework in order to be implemented in the classroom. But the focus on lab skills does assume some basic understanding of a few major concepts related to the laboratory experience. *It is assumed that students will have some familiarity with the graphing process.* Students should know how to construct a graph at the level typical of a science learner who is coming into AP Biology. Students should have some familiarity with the different types of graphs that are typical of science lab experiences (e.g., line and bar graphs), and should understand why one type of graph is used instead of another type. We also assume students have some familiarity with modern computational graphing tools such as spreadsheet-based graphing programs.

If instructors feel that some time needs to be spent addressing student conceptions in any of these areas, they should do so prior to beginning this lesson. We have provided some reference activities and resources instructors may find useful in the resources section of this curriculum module.

Common Student Misconceptions

From a science practice standpoint, many students come into AP-level science courses without ever really spending any time considering how they graphically represent data. From a mechanics standpoint, most AP-level students are able to construct a graph without too much difficulty. But the choices students make when constructing graphs is often based on expedience rather than aesthetics. Students do not realize the graph is the major visual display of information in a lab activity, and as such, students are frequently unable to justify why they decided to implement particular elements in their graphs or charts. Students also do not realize the range of options available to visually represent data.

Additionally, students tend to indulge in what Edward Tufte has termed “chart junk”: the inclusion of various extraneous and complicating visual elements in their graphs. The presence of chart junk in a graph does not increase the aesthetic or scientific merits of the graph, and typically just confuses the presentation of the data. Fundamentally, good information visualization is rooted in simplicity and elegance, with conscious consideration, both in form and style, of all of the elements represented in a particular graph. Contemporary information graphics (several examples of which are presented in Appendix D) are not only cleanly designed but also use principles of design to present information in the *most compelling* (and often most surprising) way possible.

Teacher Learning Outcomes

As a result of this lesson, instructors should expect students will be able to produce graphical representations of data that are better designed. Students should be able to justify all of the choices they made when constructing a graph (by which we mean that they will provide a claim and support that claim with evidence and reasoning), and explain how those choices aid the presentation of the information in a particular data set. Students will also be able to analyze a particular graphical display of information and make recommendations for refining it.

Materials or Resources Needed

- Data set
- Graphing applications, or graphing tools (if done offline)

Activity 1: Presenting Information: Process and Analysis

The instructor begins the activity by presenting students with a data set (see Appendix D). In addition, the handout includes a series of prompts related to the data set, designed to help student frame their thinking about how they plan to graph the data set prior to the actual graph construction.

Instructors should not feel the need to use the supplied data set for this activity. Depending on instructional circumstances, they may choose to utilize a data set generated by the class during the course of a class laboratory activity, or other, similar data sets. Also, instructors may choose to assign this first part of the activity as homework as time considerations warrant. The included data set is not too cumbersome but still allows for a healthy amount of optional student manipulation. Ideally, students would center on graphing cumulative hatch rates over the span of time represented in the data. Similarly, the data set is somewhat ambiguous as to whether a line or bar graph is the appropriate mode of display.

Using their responses as a guide, students are asked to graph the data set. This should be done independently so the graphs are the work of individual students and do not represent group efforts.

Instructional choices as to how students will be required to graph this data set are really dependent upon instructional circumstances and the student population. Many students are unfamiliar with the process of using a spreadsheet graphing program to construct a graph. If they choose to have students utilize a spreadsheet for graphing this material, instructors should anticipate needing to spend more time dealing with students' lack of skills on particular spreadsheet software. Similarly, while spreadsheets are a widely used mode of graph construction in scientific endeavors, the AP Exam will require students to construct a graph utilizing pen/pencil in physical space. This is not to discourage this choice by the instructor. Computer-based graphing is the major mode of graph construction students will be expected to use in their continuing education, and as such, this activity can provide a valuable opportunity for students to become more familiar with graphing programs. At the same time, many computer graphing resources may overly restrict the options that students have in terms of bringing visual elements into their graphs. Many typical graphing programs constrain user options for many of the reasons that are discussed in this module. Resources for using several popular spreadsheets to construct graphs are provided on page 35.

Our instructional structure on having students graph the data individually is similarly only a strong suggestion. There are certainly viable instructional modes for this activity that would have students working in a more collaborative fashion in producing their graphs. The only concern in having students collaborate in group graph construction is in the possibility that not all students working together will gain equal understanding of the design principles that the lesson endeavors to impart.

Utilizing the graphs they construct, students analyze their work and the work of their peers. Instructors may choose a wide variety of strategies to conduct this peer analysis. Instructors may elect to have students present their graphs to one another in either a small- or whole-group setting. Students may volunteer to present their work, or the instructor may choose specific students to present their specific graphs. (If instructors utilize this latter option, they may find utility in collecting student graphs at the conclusion of Activity 1.) Regardless of the particular presentation format, students should be asked to address the following points during their presentations/peer feedback sessions.

- Why did you choose to represent the data the way that you did?
- Why do you think your choices are effective?
- Are other students able to read the data correctly?
- Are there unnecessary visual elements?

Instructors should take care to make sure all interactions in these feedback sessions are constructive. It should be understood that, since no one is an expert in design, no one is immune from criticism. Design is an iterative process that is never completely or totally optimized. At the same time, there are constructive — and not so constructive — ways to offer feedback. If, at any time, instructors feel the character of the conversations drifting to a nonconstructive mode, they should be quick to refocus the discussion. Similarly, it is important to remind students that the construction of a graph is really only the first part of a two-step process. Certainly, graphs make the visual representation of information possible, but it is the questions and discussion of graphs that lead to understanding the phenomena under consideration.

Following this feedback opportunity, students are asked to reflect on the graphs they have seen, and to respond to a series of prompts related to the elements they liked and did not like.

Using student responses to the prompts related to appealing and unappealing elements of the graphs, the instructor leads the class in a whole-group conversation about the principles of good design. A series of principles of graphic design are established.

The next pages offer a list of major principles of graphic design that may aid instruction:

Emphasis: Drawing the viewer's attention to the most important point or points. There are a number of ways to establish this.

- **Size:** The size of a graphic element can draw the viewer's attention toward it or away from it.
- **Shape:** Students should consider whether shapes should be complex or simple, organic or geometric. Shapes can also be used iconographically. To use an obvious example, the shrimp listed in the data set could be represented by a shrimp icon (whatever that might look like).
- **Placement:** How is a graphic changed when certain elements are placed in the center versus being featured off-center or on the periphery of the page?
- **Contrast:** This is the juxtaposition of opposing elements in order to reinforce each. These can be opposing sizes, shapes, or colors (see above) highlighted by their placement relative to each other.
- **Color:** When using color, there are a number of aspects to keep in mind:
  - **Color Temperature:** The warm/cool property of color could relate to actual temperature as in the data set provided. However, it is important to remember that warm colors advance, cool colors recede. You don't want a background color to overwhelm (and thus remove emphasis from) a foreground or important element.
  - **Hue (or Intensity):** The greater the intensity, the more emphasis.
  - **Complementary Colors:** Colors that are opposite on the color wheel that reinforce (or emphasize) each other —red/green, blue/orange, yellow/purple.

When thinking about emphasis as relates to the design of graphs, the scale of axes and the style, color, and placement of elements (title, legend, labels, etc.) are all factors that need to be considered.

Balance: Arranging the elements in order to create stability. There are two types:

- **Symmetrical:** Arranging elements equally around a central axis (bilateral symmetry), or around a central point (radial symmetry — e.g., a spiral or flower).
- **Asymmetrical:** Arranging elements of differing visual weight to counterbalance each other on the page.

Unity: This refers to the visual coherence of the whole design. All of the visual choices (color, placement, contrast, balance, etc.) should be working together to create harmony. When thinking about unity as relates to the design of graphs, care should be taken to make sure that all elements (fonts, color choices, plot points, etc.) are synchronized.

Again, ultimately the successful design will display visual unity while adhering to the aforementioned guiding points: *Less is more. Form follows function.* This will result in an elegant, easily read, aesthetically pleasing visual document.

The instructor should not feel a need to establish all of the above principles during the course of the whole-group conversation. Depending on the nature of the conversation, the instructor may choose to omit principles that do not develop organically during the discussion, or supplement the enunciated principles with less emphasized ones at the conclusion of the conversation. Obviously, the spirit of these principles is what is important, not the specific language that is offered above.

Instructors may also find it helpful to analyze a few of the student graphs following the group conversation and discuss how student work samples adhere to/deviate from the principles of design that are described above.

To conclude this activity, students are asked to reexamine and revise their graphs. They will identify at least one element in their “first draft” graph that could be better represented and change it.

Activity 2: Presenting Information: Expanding the Possibilities

After the conclusion of the first activity, the instructor introduces students to a variety of information graphics. We have supplied some resources in the reference section of this module that instructors can use to help them choose their formats. Here are some suggestions:

- Tree maps
- Flow charts
- Venn diagrams
- Time series

Samples of these graphs are provided in Appendix D.

Students are asked to consider what makes a particular graphic effective for a particular purpose. What, if anything, makes these examples different from the graphs students just created? Instructors revisit the list of visual elements and principles that were discussed in Activity 1. Students consider particular formats in terms of the principles of graphic design and identify the elements of a particular infographic format that make it most effective.

Instructors should feel free to style this conversation in whatever mode with which they are most comfortable. Students can discuss in a whole-group setting or work in small groups. Students can discuss all of the formats that the instructor brings into the conversation, or can consider individual formats before reconvening to discuss their observations with the larger group.

Following this conversation, students are tasked with applying an infographic format that the class has discussed to a novel data set. *Instructors can supply students with a new data set directly, or students can be tasked with supplying their own data set, either from a laboratory activity or from online discovery. We have supplied some data set resources in the appendix for this activity.*

Students engage in a planning period where they consider their choices and explain their decision-making process. During this time, they must consider what is *most* important for viewers to *immediately and clearly* understand about this data, and then consider which elements and principles of design, and which graph type, can be utilized to highlight this key information. Following this planning period, students create their infographics.

After creating their infographic, students are asked to compare the process and results of Activity 1 and Activity 2.

Formative Assessment

This lesson provides multiple avenues for formative assessment. Aside from informal questioning, student responses to the prompts in the instructional materials allow instructors to monitor student conception of the material under consideration. If, at any time, instructors feel that student responses to prompts or their responses to questions are underdeveloped, instructors should endeavor to reinforce and reteach any of the content at issue.

The discussion/presentation peer-feedback session serves as an important formative assessment point for this lesson. Instructors should expect that students will be able to provide articulated answers to the discussion questions (particularly since students are provided with prompts to help them organize their thinking prior to the presentation). Instructors may also find merit in requiring students to take notes during the discussion, with explicit instruction about elements of the graphs that students find useful, interesting, or otherwise indicative of good design. Notes can serve as an additional artifact that instructors can use to assess student understanding.

The graphs that students generate during the course of this activity, and the response that they provide at the conclusion of the activity are similarly informative when assessing student conceptions of informational presentation as it relates to principles of design. Instructors should expect students will be able to identify at least one aspect (and hopefully more than one) of their "first draft" graphs that can be refined, implement that refinement, and justify the choices they make. Instructors should address students who don't demonstrate the ability to revise their graphs and if the second iteration of the graph does not represent a clearly articulated attempt to address a particular aspect of design (or if the second iteration seems to be moving further away from good design). Instructors should use their discretion in determining how to address the issue, but a private conference with the student in question may be a particularly fruitful avenue to pursue.

Reflection

As instructors reflect on this activity, two major conclusions can be reached: Either students are demonstrating improved design sense when constructing graphs, or they are not. In the first case, the obvious next step would be for instructors to connect this process to the rest of the AP Biology laboratory experience, and make clear the expectation that the design standards discussed in this activity represent the basis by which the graphing that they will do over the course of the year is evaluated. In the second case, instructors can decide whether the lack of development requires immediate reteaching of the material that is covered in this lesson, or if students will be better served by returning to this process (in whole or in part) as students continue their laboratory experiences in the course, and continue to generate data sets that need to be graphed.

If instructors are interested in expanding this lesson further into the realm of design and information visualization, there are a host of resources that instructors may wish to include in their class. We have provided several resources and Web links for further investigation in the resources section of this module.

Summative Assessment

The nature of this curriculum module makes a cohesive, overarching summative assessment a difficult proposition. While we will certainly not discourage any inventive educator from being able to wrap these four lessons together into some sort of overall mini-unit on “modeling” (in which case, please let the authors know about your approach!), we do not think it is the way the vast majority of instructors will interact with the lessons.

That noted, each lesson does provide an artifact of student understanding that can serve as a summative assessment of student learning.

Curriculum Module Summary

Learning Outcomes

This module provides instructors with several opportunities to bring visual modeling into their AP Biology instruction. Each opportunity is different, and each one demonstrates a useful application of visual modeling that should help student conception in ways that simple mathematical or verbal descriptions don’t. None of them occupy a major portion of course time. By engaging in these activities, students will be able to develop their understanding of difficult concepts from the course, and improve their ability to design and present information to their peers. These activities will also require students to engage their creativity in a manner that will broaden their scope of communicative choices. With modeling as such an important component of the curriculum framework, both as a science practice and as the focus of multiple learning objectives, students who participate in these activities are provided with new constructs to help their understanding of materials from the course.

Next Curricular Steps

This module is only a sample of how instructors may think about bringing the practice of visual modeling into their classroom. Instructors should not feel limited by the activities of this module, and are encouraged to broaden the activities that are presented in whatever manner they feel is appropriate for their instructional circumstances. The types of visual models that have been demonstrated in this module can easily be used across multiple units of the course, with minimal modification.

Teachers are encouraged to consider the various interdisciplinary connections between these activities and what students may be doing in their art classes. With a modicum of preplanning, biology teachers could utilize art teachers as resources regarding artistic processes appropriate in a biology class setting. A willing art teacher could, for example, provide materials, technical assistance, or perhaps be brought in as a co-teacher for an art-related lesson. As teachers of a creative, nonscientific subject, art teachers might also suggest alternative organizational strategies and assessment methods when utilizing artistic processes.

References

Tufte, Edward. *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press, 1983.

Resources

Lesson 1:
http://www.chuckclose.com
The home page of Chuck Close includes samples of his work.

Lesson 2:
An example of visual modeling of how evolution affects the phenotype of individuals in a population:
http://learn.genetics.utah.edu/content/variation/comparative/

Lesson 3:
How to Graph

- All About Graphs: The Open Door Web Site http://www.saburchill.com/IBbiology/graphs/001.html
- Using Google Docs to make graphs http://support.google.com/docs/bin/answer.py?hl=en&answer=63728
- Infographic Creation Tools: These online infographic construction tools require free accounts to be utilized. http://infogr.am
- Infographics and data visualization http://visual.ly

Data Visualization Resources

- Gallery of Data Visualization: http://www.datavis.ca/gallery/index.php
- Information Is Beautiful: http://www.informationisbeautiful.net/
- We Love Infographics: http://weloveinfographics.info/

Bozeman Biology Video Clips for Lessons 1–3:

Lesson 1:
Cooperative Interactions
http://www.youtube.com/watch?v=djtc7WUmT_c&list=PLFCE4D99C4124A27A&index=58&feature=plpp_video

Lesson 2:
Natural Selection http://www.youtube.com/watch?v=R6La6_kIr9g&list=PLFCE4D99C4124A27A&index=2&feature=plpp_video

Examples of Natural Selection
http://www.youtube.com/watch?v=S7EhExhXOPQ&list=PLFCE4D99C4124A27A&index=3&feature=plpp_video

Genetic Drift
http://www.youtube.com/watch?v=mjQ_yN5znyk&list=PLFCE4D99C4124A27A&index=4&feature=plpp_video

Appendix A

Lesson 2: Worksheet/Planning Guide for Students

Population:

Evolutionary mode:

What effects does your selected evolutionary mode have on your selected population? Use the following chart to note the features that will change from one stage to the next.

Pre	Post

Your next task is to find a way to visually convey those changes. Use the following questions to help you plan your visual model:

- Begin by considering your "pre" evolution mode. Decide which elements should be visually emphasized. *How* will you emphasize them? Through the use of color? Adjusting the size? By incorporating collage elements? Some combination of the three? Something else entirely? If you choose to collage, simply cut the pertinent sections of your reference out and paste them in the appropriate area. You can combine this with your hand-drawn elements to create a *multimedia* artwork.
- If your mode is internal, you could draw an "X-ray" view of the appropriate area. Once you are satisfied with your overall design, tighten the drawing with more deliberate lines and details as needed.
- Begin your "post" evolution mode by taking a second piece of paper and tracing the outline of your original design. (You may use a light box if you wish.) Alter the pertinent details using the same process as above.
- Optional: Neatly label the emphasized features of both drawings.

Appendix B

Lesson 3: Visualizing Data

Presenting information: Process

The following data is from an experiment to determine the effect of temperature on the hatching rate of brine shrimp (a hybrid population of several species of the genus *Artemia*). An initial number of cysts were deposited in petri dishes that were then held at five different temperatures for the duration of the experiment. At 24-hour intervals, the total number of brine shrimp that had hatched were counted, and all hatched individuals were removed. For the purpose of this activity, assume that all experimental protocols and procedures were valid, and that there were no notable sources of error.

Temperature (degree Celsius)	Total number of cysts on day 0	Day 1 hatched cysts	Day 2 hatched cysts	Day 3 hatched cysts	Day 4 hatched cysts
24	73	0	5	9	5
26	72	2	15	18	16
28	70	1	16	20	19
30	76	2	7	10	6
32	72	0	1	1	0

You will graph this data set. Before you graph the data set, answer the following series of questions:

- What kind of graph do you think is appropriate for this data? Why?
- Will you graph this data "as is," or will you process the data before graphing it? Explain the reasoning behind your choice.
- Briefly sketch what you think your graph is going to look like in the space below.

After you have answered these questions to your satisfaction, graph the data set.

Presenting Information: Analysis

After you complete your graph, take some time to respond to the following questions:

- When we graph data, we have to make choices. Explain three of the choices that you made in your graphing, and why you made these choices.

- Do you think any of the choices you have made in constructing your graph should be revised? Why or why not don't you feel this way?

Appendix C

Lesson 4: Visualizing Data
Peer Feedback Guide

Your teacher will explain the procedure for presenting and discussing your graphs with your peers. In general, it is important to be able to explain the choices you made when constructing your graph, and to expect that your peers should be able to do the same. Be constructive in your feedback. Please ask questions and make comments related to the elements of the graphs that you think are interesting or that you are confused about. Feel free to make suggestions about how to design aspects of the graphs that you see more effectively, but remember that graphic design is a process of constant revision, and there is no such thing as "one right answer."

You are encouraged to take notes during this session.

To be addressed after following the feedback session:

1. Consider the graphs you thought were appealing. Why do they appeal to you?
2. Consider the graphs you thought were unappealing. What about them was unappealing to you?

Principles of Design

Together with the class, you are going to develop a series of good principles to keep in mind when creating information visuals. Write the principles that the class comes up with below.

Revision:

Revise your graph using the principles of design the class developed. Choose at least one element of your graph that you think could be improved, and work to improve it. Compose a brief written response that addresses the following points:

- Describe the element(s) you decided to change and why you decided to change it/them. Relate your answer to the principles of design.
- How did you change the element(s)? Why are your changes more effective than the element(s) were before you changed them? Relate your answer to the principles of design.

Appendix D: Sample Information Graphics

Tree Map

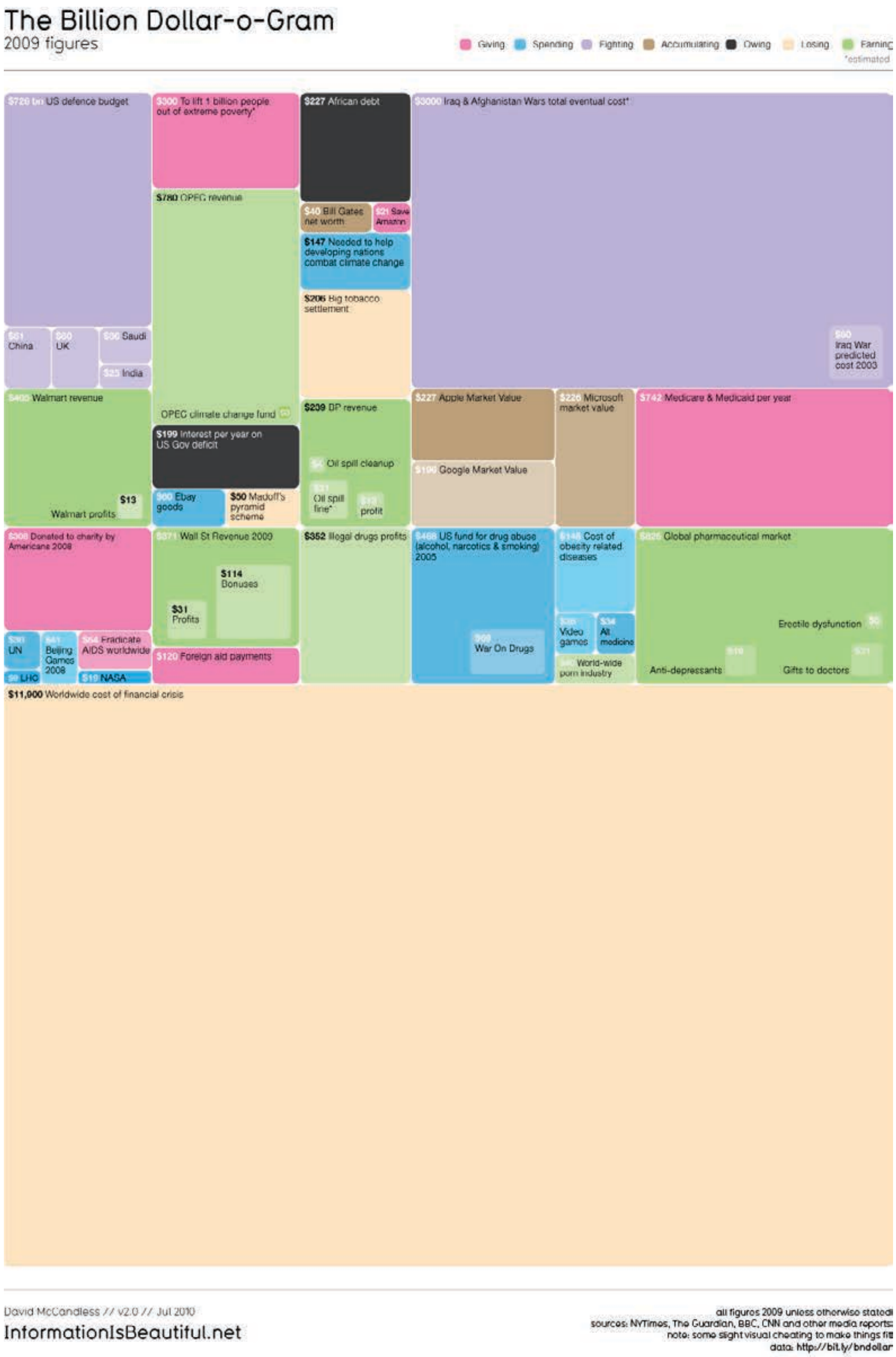

image via: www.informationisbeautiful.net/visualizations/the-billion-dollar-o-gram-2009/

Flow Chart

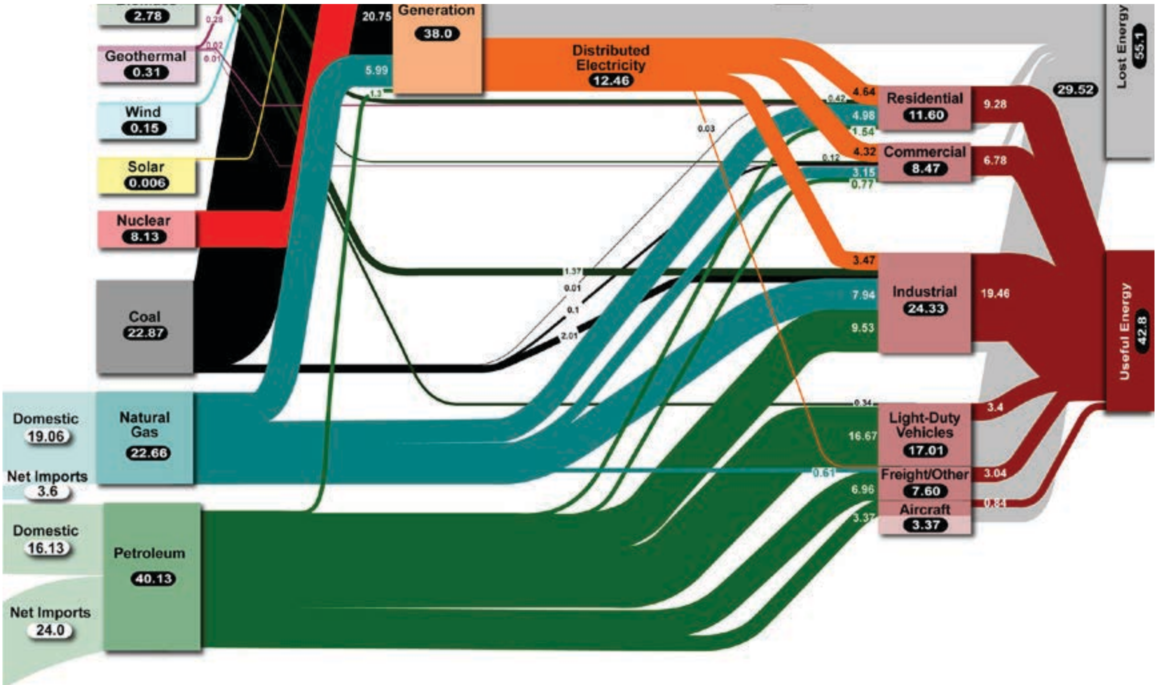

Image via http://www.noelsusskind.com/blog/wp-content/uploads/2009/03/llnl_energy_chart300.jpg

Venn Diagram

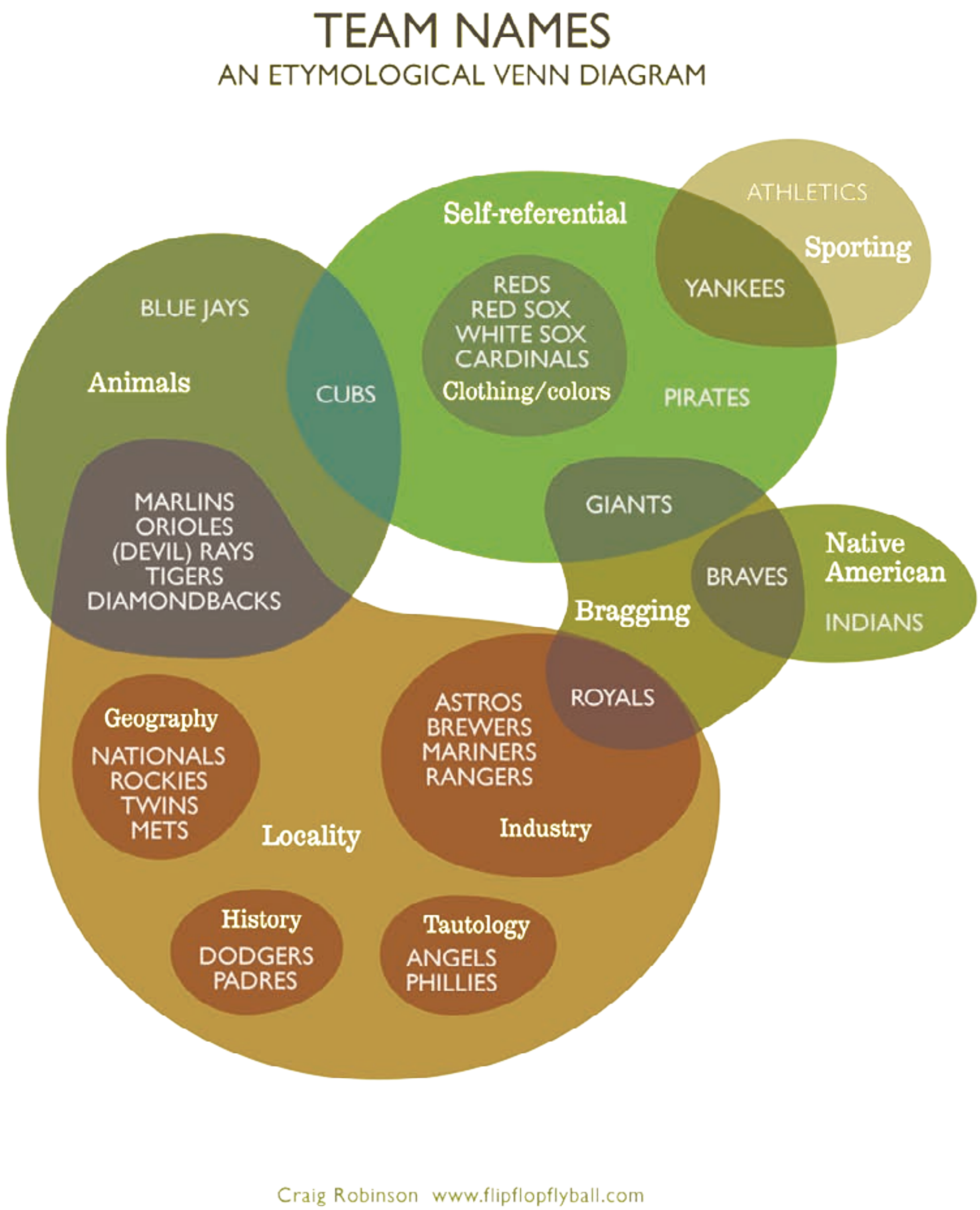

Image via: http://www.flipflopflyin.com/flipflopflyball/info-teamnames.png

Time Series

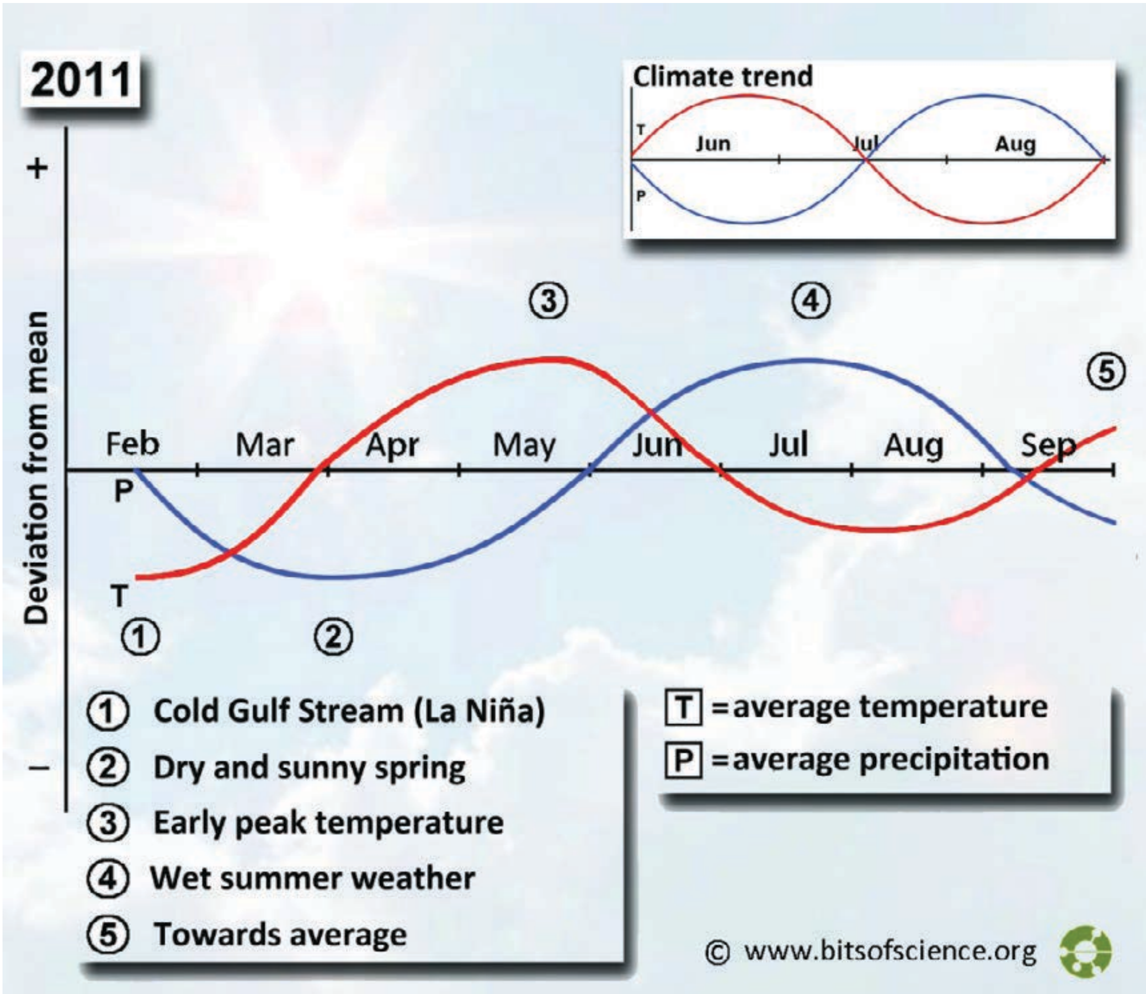

Image via: http://www.bitsofscience.org/wordpress-3.0.1/wordpress/wp-content/uploads//Trend-spring-summer.jpg

Appendix E: Correlation of Lessons in Module to New Sample Exam Questions

Lesson 1:
Section I, Part A: Questions 31, 36, 57, 62, 63
Lesson 2:
Section I, Part A: Questions 7, 8, 9, 10, 37
Lesson 3:
Section I:
Part A: Questions 4, 12, 24, 56, 61
Part B: Question 3

Section II: Question 1
Lesson 4:
Section I:
Part A: Questions 25, 32, 34, 38, 51
Part B: Questions 1, 5, 6
Section II: Questions 2, 7

Contributors

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Derek Mainhart is an art teacher at Deer Park High School and at the Usdan Center for the Creative and Performing Arts. He has taught at many institutions, including Molloy College, Boricua College, and Hofstra University. He teaches cartooning workshops in the greater New York area. In addition, he was the first vice president of the Museum of Comic and Cartoon Art (MoCCA) in Manhattan, and was instrumental in the formation of its annual MoCCA Festival. He has organized and participated in numerous gallery exhibits in and around New York City. His self-published works include *The Iraqi Tinies* and *W*.

Melissa Manning has taught composition, English, and AP English for 20 years at the high school and college levels and is currently a faculty member at The Bush School. She has been involved in AP English as an AP English Literature Reader. She is also active in the Seattle theater community, helping to transform "great literature into great theater" as a board member of the Book-It Repertory Theater.

Peggy O'Neill Skinner has taught biology and AP-level biology for 40 years at The Bush School in Seattle, Wash. She has been involved in AP Biology as a consultant for the College Board, both as a member of the test development committee and current biology redesign committee. Skinner has been an AP Reader, Table Leader, and Question Leader for the AP Biology Exam. She is a current member and former chair of the College Board Science Advisory Committee as well as the national Academic Advisory Council. She is on the Board of Trustees of the College Board. She consults for and leads workshops and summer institutes in AP Biology for the College Board and various school districts and universities.

Marilyn Smith has taught art at the high school level for 10 years and is currently a faculty member at The Bush School in Seattle, Wash. She teaches her students a variety of media ranging from traditional black-and-white photography to printmaking, drawing, and metal design. Smith is also a working artist who paints and creates one-of-a-kind jewelry pieces.