Using Dinosaur Models to Teach Deductive Reasoning Skills in Vertebrate Biology Lab

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Abstract: Continued explosion of scientific knowledge and increased emphasis on application calls for a change in teaching methods in the science classroom. The ability to apply knowledge in a problem-solving manner to real-life situations is more important to a biology student than possessing an exhaustive accumulation of facts. Described is a teaching approach that employs three-dimensional whole animal models to teach the student how to use deductive reasoning and critical analysis to discover functional correlates of structure. Using dinosaur models, which the student finds fascinating, encourages active participation. These exercises hone communication and leadership skills, and teach students to work in a collaborative manner.

Keywords: Deductive reasoning, problem-solving, vertebrate biology, dinosaurs

Current Concerns in Science Education

Despite the availability of information resulting from recent scientific research advances, basic college student scientific literacy in the United States is still low (NSF, 1996. P. iii). The problem does not simply lie in a deficiency of scientific knowledge, but, more importantly, in a lack of skills to use the knowledge in a problem-solving manner. To be able to apply knowledge to real-life situations, students must possess good deductive reasoning and critical thinking skills, good verbal and written communication skills, as well as the ability to work in a collaborative manner. Like scientific facts, these skills are learned. Educators are recognizing the importance of limiting the amount of factual information taught, and instead are introducing into the science classroom learning experiences that hone communication skills through collaborative learning. The focus is on inquiry and problem solving rather than on memorization (Weiss, 1992-1993). Described here is a teaching approach that hones all of these skills by incorporating deductive reasoning exercises into the labs of an undergraduate Comparative Vertebrate Biology course.

Using Problem Based-Learning in Vertebrate Biology Laboratories to Address Current Concerns in Science Education

Major challenge in teaching a comparative vertebrate biology course is that the breath of issues addressed ranges from phylogenetic history, development and growth phenomena, to anatomic, physiologic and behavioral characteristics of organisms studied. Understanding the connection between such diverse topics is complicated by the fact that majority of junior students still use memorization rather than thinking as a primary study tool. The result is knowledge of a series of seemingly unrelated facts that will soon be forgotten. This problem can be circumvented by systematically incorporating into vertebrate biology course problem-based questions which require the student to critically analyze factual information presented in class, apply newly acquired knowledge to concrete situations, and seek the connection between the phenomena studied. Such exercises also teach the student how to work with the peers in a collaborative manner, and help hone verbal communication skills.
Because comparative vertebrate biology course has a significant laboratory component, it lends itself ideally to learning through problem-based, hands-on exploration. I have thus added deductive reasoning exercises to each laboratory session in which the students traditionally study skeletal material or dissect preserved specimen. These exercises consist of a set of problem-based questions that are addressed by analyzing animal models of extinct reptiles, representing whole body reconstructions of their external appearance. To find solutions to problems, the student must first understand the concepts discussed in the classroom and next be able to apply them to laboratory specimen. Since different individuals can use the same factual information in different manner, the problems often lend themselves to multiple interpretations. Thus, for example, a group of students may view a massive tail primarily as a propping device to maintain a bipedal posture during feeding from trees; other students may regard the same type of tail as a balance device for locomotion. The aim of exercises is to propose solutions that can be supported by scientific facts, rather than to seek the absolute truths.

Questions are designed so as to be also pertinent to lab assignment for a particular day and related material discussed in the classroom. They frequently refer the students to pictures of the skeleton of the extinct reptile under consideration and the articulated skeletons of various vertebrates, conveniently displayed on workbenches. To arrive at valid justifications, the students must also refer to specimen studied or dissected in the particular lab. In analyzing the questions, students often consult their lecture notes and the textbook. To expedite the process, they are sometimes referred to specific textbook pages where they can find useful information.

Using Whole Body Dinosaur Reconstructions as a Model for Problem-Based Exercises

Given the importance of the spatial relationships of the anatomical structures, and the ease with which students relate to hands-on exploration of three-dimensional objects, it is beneficial to select for problem-based exercises a three-dimensional model that can be physically explored by the student. Most importantly, the model should represent a subject matter which the student finds fascinating and stimulates a curiosity for further exploration.

I discovered by accident that a study of whole body reconstructions of dinosaurs fulfills the above requirements, while permitting exploration of a wide range of biological issues. A poster of dinosaurs and flying reptiles, displayed in the lab at the beginning of the semester, generated a surprising amount of interest among the students. They repeatedly stopped by the poster to ponder over the questions accompanying the pictures, e.g., “Which head features of this extinct flying reptile suggest that this was not a bird?” I thus promptly incorporated whole animal dinosaur models from my personal collection, charts of their skeleton, photographs of fossilized material from professional and popular journals, and a set of relevant questions into the ongoing skeletal labs. The level of spontaneous student interaction increased. They began to explore with interest the correlates between the external anatomy of dinosaur models and their skeletal features, and to draw similar structure-function correlates for modern vertebrates. Dinosaur models thus became a standard feature in vertebrate labs, from those focusing on skeletal anatomy and muscles, to those involving dissection of various organ systems.

Structure of Problem-Based Labs

A typical vertebrate biology lab is structured as described below. All labs except those dealing with embryologic development include questions based on Dinosaur models.

1. **Work on lab assignment.** During the first half of each three-hour lab period, students work in pairs on completion of their laboratory assignment. This may involve analysis of the overall vertebrate body plan, comparative study of skeletal elements discussed in class, or dissection of a set of muscles in shark, mud puppy and mink.

2. **Study Dinosaur models and address problem-solving questions.** About an hour and a half into the lab period, the students are instructed to form four-member teams, take a Dinosaur model from the demonstration table to a work area, and jointly seek solutions to the problem-based questions found with the model. As the teams analyze different animal models on display, each team member is expected to take a turn in acting as a group leader in coordinating
the discussion and taking notes on the team’s solutions to problems. Examining four to five animal models in each lab allows ample time for discussion in a class composed of 20 students.

3. **Present to the class team responses to questions.** During the last 30-40 minutes of the lab period, as team members come to a consensus on the responses to questions, each team is responsible for explaining to the class the conclusions and rationale for their analysis of one animal model of their choice. The only stipulation is that we discuss all models on display. Since the questions lend themselves to multiple interpretations, to be valid, the conclusions must be justified on the basis of scientific reasoning and concrete factual information.

All team members are expected to participate in the presentation of the group’s findings, based on division of labor planned by the team. As class discussion unfolds, the instructor may write down on the board the key words and phrases used by the students to help them recognize similarities and/or differences in the interpretation by different lab teams. The primary role of the instructor is to keep the discussion focused, help refine ideas by posing additional questions, and help summarize the outcome of class discussion.

**Examples of Deductive Reasoning Exercises**

A sample of problem-based questions follows. The questions are designed to reinforce the focus of each laboratory assignment and complement theoretical issues discussed in class.

1. **Can the external anatomy of the head tell us, which sensory organs were of importance for the survival of the following extinct reptiles: *Pterosaur*, *T. rex* and *Stegosaurus*?**
   a. Which characteristics of the head suggest that *Pterosaur* had a better visual acuity than *Stegosaurus*? Based on the external anatomy of the head, what would you conclude about *T. rex* in that regard? What features of the head generally suggest a relatively good sense of smell? How do these three extinct reptiles compare in that regard? (The expectation is that the student will draw conclusions by comparing the overall size of the head to the relative size of different head regions housing special sensory organs (e.g., the size of the eyes or the snout). The role of the sensory organs for animal survival in different habitats (arboreal vs. terrestrial, etc.) has been discussed in class.)

b. Based on your conclusions regarding dependence of the three extinct reptiles on their visual sense, propose how differences in visual acuity affect an animal’s way of life. Justify your answer. (Students may decide to consider how an animal’s visual sense correlates with its ability to identify food source and other targets of interest. They may propose that a reasonably good visual acuity in a *T. rex*, thus capability to recognize prey at a distance, would serve a useful purpose only if a strong musculo-skeletal system co-evolved to support running to catch the prey.)

c. Which features of the head skeleton of the three extinct reptiles support your conclusions regarding their dependence on the visual sense for survival? How do these compare to distinguishing characteristics of the head skeleton of a pigeon? (Reader: consult Fig. 1.) (Students will likely recognize a relatively large orbit size in *Pterosaur* and the pigeon, but not in *Stegosaurus* and, to their surprise, *T. rex*. As they debate a relatively small orbit size but well-developed nasal bones in *T. rex*, they begin to question whether this reptile may have also used the sense of smell for hunting. They may further decide to compare the anatomy of the occipital region and notice that, unlike the pigeon, these two extinct reptiles are missing the occipital prominence. Based on class discussion of the functional significance of major external features of the skull in relation to development of the occipital or olfactory regions of the brain, the students may propose the evolutionary changes in development of the brain of modern birds as compared to extinct reptiles.)

**Timetable:** Questions a. and b. can be addressed early in the course as vertebrate body plan and the principal characteristics of various vertebrate classes are discussed. The same animal models should be revisited later in the course as vertebrate head skeleton is studied, to address question c.
Figure 1  Comparison of the head skeleton of three extinct reptiles and the pigeon.  

a. Pterosaurus:  Large orbit size relative to the skull is the anatomical correlate of large eyes and a keen sense of vision. Absence of the occipital prominence suggests poorly developed occipital cortex and simple processing of visual information.  

b. Stegosaurus: Small orbit (o) in comparison to overall size of the skull is indicative of a relatively poor vision.  

c. T. rex: Small orbit (o) of this massive skull suggests that this animal may not have had a very acute visual sense. Prominent nasal bones signal a relatively large area housing the olfactory epithelium.  

d. Pigeon: Unusually large orbits correlate with keen visual sense, while slender nasal bones and reduced nasal compartment correlate well with poor olfactory sense.

2. Did flying reptiles evolve the anatomical prerequisites for true flight? Compare Pterosaurus to modern birds and flying mammals.  

a. What anatomical features of a take off mechanism can you find in the Pterosaurus animal model? What suggests that this reptile could not have used its hind limbs for take off? Compare its skeleton to that of the pigeon and propose how differences in skeletal anatomy correlate with differences in take off mechanisms.  

[The student is reminded to compare details of the animal model’s external anatomy (wing claws in this case) to the skeleton in the same limb region. Early in the course, before limb skeleton is discussed, the student is already able to recognize that finger bones appear rudimentary in the pigeon. The student also recognizes that the relative size of the hind limbs, and presumably limb bones, in two animals differs.]  

b. Which features evident on the Pterosaurus model suggest that this animal was better adapted to soaring than to true flight? Justify your answer.  

[The student may note the presence of a beak with teeth. In line with weight reduction principles discussed in class, the justification would imply recognizing that the jaws with teeth are heavier than a toothless beak. Wing specimens are provided to prompt the student to use the weight argument when comparing a skin membrane to a true wing. Students never fail to wonder about the light weight of the large wing specimen.]  

c. Study the Pterosaurus model and the picture of its skeleton. Also study the preserved bat specimen and the skeleton of the pigeon. How does the attachment of the wing membrane to the limb skeleton compare to the attachment of the flight feathers? Which of the two shows more extensive attachment to the skeletal elements and why? Can one justify the observed differences on the basis of differences in physical characteristics of skin membranes vs. true wings?  

[The expectation is that the students will recall from class, that skin is heavy and prone to tearing. A student may use this argument to propose that a skin membrane requires more extensive anchoring than a true wing.]
**Timetable:** Questions a. and b. can be addressed early in the course but should be also revisited later on, once the skeleton or organ systems (e.g., the integument) have been discussed. Knowledge of skeleton will permit more detailed analysis of anatomy of the limbs, thus allowing the student to draw more precise structural correlates with function. Question c. should be addressed after the limb skeleton has been discussed to allow the student to make more accurate observations. At that time the student will be prepared to bring into the discussion more subtle points, e.g., the possibility of the presence of pneumatic bones in *Pterosaurus*.

3. Can one deduce from the external body anatomy how quickly dinosaurs could run? Compare *Triceratops* and *Stegosaurus* to alligator.

a. Which body features evident on animal models suggest that *Triceratops* was a quicker runner than *Stegosaurus*, despite the fact that both animals were very heavy? Consider the same body features in the alligator, and propose how its speed of locomotion compares to the presumed running speed in the two extinct reptiles. Justify your answer. Propose what makes the rhinoceros a good runner despite its heavy weight and relatively short legs?

[based on class discussion of integumentary and bony specializations of the head in Ungulates, the student may use parallel reasoning to propose various functions for *Triceratops* horns. Additional questions by the instructor may help the student relate skull puncture holes to fights for mate selection.]

b. Could *Triceratops* have used its massive frill as a protection device? Consider its plane of orientation and its position relative to body regions that need extra protection. Since a major function of large bony surfaces is to provide the site for muscle attachment, could this argument be used for interpreting the functions of the frill? Consult the picture of *Triceratops* skeleton and justify your reasoning.

[The student may view the frill as a protection device, but would encounter difficulty in proposing justifiable behavioral tactics that would permit the use of the frill as a shield for vulnerable parts of the body, the head and the chest. Regarding the second question, the student will likely attempt “to hook” some of the nearby muscles, e.g., jaw and perhaps neck muscles, to the frill. The justification would imply looking for the evidence of skeletal specializations on the frill (e.g., bony ridges for muscle attachment) in support of this argument. To help the students arrive at stronger scientific arguments on the basis of parallel thinking, the teacher may pose additional questions, e.g., “What could be the functional significance of

4. **What can head skeleton specializations of extinct reptiles tell us about their behavior and social life?**

a. Compare position, shape and size of *Triceratops* horns to similar structures in living Ungulates. Propose multiple functions for *Triceratops* horns based on what you know about their function in Ungulates. What function is suggested by the following observation: head fossils of male *Triceratops* show puncture holes that match the size of two large *Triceratops* horns.

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### Questions

The pronounces occipital ridge in the primate skull in our collection? The students may propose that the strong neck muscles attach to bony ridge.

- c. What could have been the function of the prominent bony ridges along the dorsal edge of the orbits of T. rex and other similar carnivorous dinosaurs in our collection? Justify your answer.

**Timetable:** Questions a., b., and c. can be addressed early in the course when vertebrate orders are discussed from a holistic prospective. At that time the student already understands the principal anatomical correlates of function (e.g., using horns as a weapon, or to create illusion of a larger body size) and recognizes their relationship to animal behavior and social life (e.g., using horns to ward off enemies, or attract mate). Questions a. and b. should be revisited later when the student dissects the muscles and become familiar with the muscle attachments to skeleton. At that time the student will be able to understand the relationship between the jaw muscles and head skeleton and provide more scientifically sound arguments in support of the proposed function of head specializations. The same questions can be addressed as the importance of skin derivatives for survival is being discussed.

### Some other issues that can be particularly well addressed on dinosaur models

What are weight reduction mechanisms in flying reptiles and terrestrial dinosaurs of large size?: Were dinosaurs built for strength, speed or both?: What are the advantages and disadvantages of large body size?: What is the functional significance of various body decorations?: What is the reason that Sauropods with long necks also evolve long tails?: How could a small-headed Stegosaurus have consumed enough food to support its weight?: What does the size of the body cavities tell us about the internal organs?: What were some of the multiple functions of tails in dinosaurs?

### Laboratory Resources

To allow students to make accurate observations, it is essential that the models come from a reliable source and have anatomically correct proportions. Our best models, expensive but made of high quality durable plastics, are scaled-down replicas of the Smithsonian dinosaur model collection, purchased in gift shops specializing in science museum items. Other models, also accurately built but lighter and more prone to damage, come from a cheaper source: Safari Limited, P.O.Box 630685, Miami, FL 33163.

### Changes in Course Structure

To create ample time for analysis of problem-based questions, laboratory component of the course has undergone substantial modifications. Some of the traditional lab exercises had to be eliminated. We no longer dissect abdominal and hind limb muscles. Musculature of both appendages is discussed in class, but dissection done on front limb only. Some of the laboratory material studied in the past had to be reduced. In the study of palatine complex of the skull we now identify only a few major bones and emphasize the overall position of the palatine shelves in relation to their function, instead of identifying all skeletal components of the two palates. Tedious dissection of fine muscles in Necturus has been reduced to larger, more readily accessible muscles. When dissecting major blood vessels of the limbs in the mink (e.g., subclavian or iliac arteries) we dissect their origin and identify their general targets but no longer trace their branches. Given the importance of deductive reasoning in acquisition of knowledge, the above course modifications in course content proved to be a worthwhile sacrifice.

### Assessment of Learning

Student responses regarding the effect of problem-based exercises on their learning have been consistently positive. They include statements: “I think dinosaur exercises made the mechanics of locomotion easier to understand.”; “Dinosaur questions really helped me understand why do you always emphasize all that conceptual stuff in lectures; “Being challenged to think made the lab interesting.”; “I like the idea of having to take turns as a group leader. That helped me personally, since one person in my group always tried to take control.”; “Having to go back and forth between the skeleton and the model really helped me see the connection.”; “I always found anatomy boring. When we worked from models we had to think about the live animal. That made it [anatomy] really fun.”; “I wish we had more thinking exercises like these in other courses.”; “I think my lab grade improved because dino questions helped me understand how musculo-skeletal system works”.

I have taught this course to a class of 35 to 40 students for eight years. Problem-based exercises were
added to the course for the past three years. The average percentage of students/year earning grade B during these three years was 42%, as compared to the 29% average for the five years before inclusion of exercises into the course. The average percentage of students earning an A grade did not appreciably change in the course of eight years. However, the average percentage of students earning grades C, D, or failing the course was 45% for the three years after the introduction of the exercises into the course, as compared to 60% average for the five years before.

Discussion

The challenge in teaching a comparative vertebrate biology course in an age in which the students most readily identify with terms “molecular biology” or “genetic engineering”, is that many students take the course only because it is required. Introducing dinosaur models into the lab early on stimulates students’ curiosity about the course. Positive student responses to introduction of dinosaur reconstructions into the lab suggest that this is an efficient model for teaching a variety of useful skills. The unmatched diversity in dinosaur adaptations and the large variety of the available models make dinosaurs particularly suitable for addressing a diverse array of biological questions, ranging from structure-function correlates to behavioral and social organization issues.

Thinking is the instrumental part of learning and the prerequisite for understanding abstract concepts. However, the majority of biology undergraduates relate more easily to concrete than to abstract. Questions based on models that can be physically explored by the student introduce thinking exercises into vertebrate labs in an unobtrusive manner. Since these exercises do not require coming up with the “correct” answers, the students do not find them intimidating and learn to enjoy them. They are quick to learn that “dinosaur questions” reinforce the concepts discussed in class and observations made in the lab, and thus increase the chances of improved performance on both written and practical exams. Improved student performance on exams after the introduction of interactive exercises based on dinosaur models, suggests that this approach to learning is particularly beneficial to the student who has difficulty with the course content and is more likely to earn a lower grade. Student’s responses to introduction of problem-based exercises suggest that they are helping them discover the importance of mastering thinking skills. This confirms the observation of Weiss (1992-1993) that one of the best ways to convince students that thinking skills are indeed necessary is to show them that thinking and learning are connected.

Incorporating deductive reasoning exercises based on whole body models has multiple benefits for the student. Questions that accompany the models call for justification on the basis of scientific arguments, and thus encourage reasoning and interpretation. Such exercises enhance students’ ability to handle abstract ideas. As in the problem-based learning model described by Barrows and Tamblyn (1980), a beneficial lesson for the student in exercises involving thinking is that scientific judgment cannot be based on personal opinions but must be justified on the basis of scientific observations. Revisiting the same dinosaur models later in the course, as students’ knowledge increases, helps the students recognize the weakness of prior arguments (e.g., “Pterosaur could probably see well because it had large eyes”). Students also discover that new knowledge empowers them to make more accurate scientific interpretations (e.g., “Pterosaur must have had keen vision because its large orbits, relative to the size of skull, could accommodate a large retinal surface needed for increased visual acuity”). Sundberg and Moncada (1994) reported that undergraduates gain similar insights when engaging in problem-solving, investigative laboratory exercises.

Using dinosaur models to address problem-solving questions helps maintain a holistic view of vertebrates as organisms adapted to specific habitats. This holistic perspective is easily lost as the students dissect organ systems and address more technical issues. By revisiting whole animal models, they begin to view each system not as an end in itself, but as a part of an individual experiencing development and growth, behavioral responses to stimuli, and interaction with other living things in its habitat. If this link is to be recognized by the student, the instructor may have to stimulate class discussion by providing additional information that excites students’ curiosity for further analysis. For instance, one can re-examine Saurischian models as one dissects major blood vessels. If one mentions, as the students dissects large neck blood vessels, that the giraffe pumps sufficient blood to its brain with the help of multiple hearts in its neck, they begin to wonder whether the same may have been true.
for the long neck Saurischians. This may in turn lead to a discussion of whether these animals grazed only from tall trees, given that giraffe sometimes grazes on the ground. Further brainstorming may lead to questions about what food was available in the habitat of these long-necked beasts and whether the competition for the same food resources may have played a role in the evolution of the long neck.

The key to learning is finding the connection between the known and unknown. If the student is to maximally benefit from exercises involving discovery of new relationships through deductive reasoning, it is important to formulate the questions so that the student can draw from prior experience and knowledge, as in the case study approach in teaching biology reviewed by Waterman (1995). This may require considerable insight on the part of the teacher, since the questions must direct the student to approaches to problem they may not readily consider. For instance, as the students ponder over differences in the use of hind limbs by various dinosaurs, it is helpful to suggest to the students that they compare the relative length of thigh and shank bones on pictures of a dinosaur skeleton to that of different vertebrates from our skeleton collection. Linking the known to unknown expedites the learning process by providing the students with an opportunity to arrive at the conclusions on the basis of what they already know.

In described approach to learning, students hone their leadership and communication skills, by taking turns as group discussion leaders and by participating in presenting team interpretations to the class. Welty (1989) observed that effective use of discussion as a learning tool requires allowing the students a fair amount of authority. Likewise, I found that students show greater willingness to engage in conversation when a good deal of the control of discussion is in their hands. As different lab teams begin to exchange ideas, discussion often moves away from its initial focus. It is important to recognize that students benefit from such side explorations. If one attempts prematurely to bring the discussion back into focus, spontaneous exchange among the students often stops.

An important benefit of addressing problem-based questions as a team is learning how to work in a collaborative manner with other group members. Since I have instituted dinosaur-based exercises, I have noticed an increase in spontaneous peer interaction and coaching. To guard against a student taking over the discussion and control of the group, it is important to rotate members responsible for coordinating group discussion.

For maximum benefit to the student, lab classes should be kept small, 20 students or less. Higher mean SAT scores for high school students that attend smaller classes suggest that the quality of learning improves as class size decreases (Ghosh, 1999). This most likely reflects the fact that smaller class size allows for more discussion and contact between the individuals.

Dinosaur lab exercises have a positive impact on teacher, as well. They help develop a bond between the student and the teacher by encouraging the exchange of ideas. After listening to student interpretations, the teacher often begins to see things from a different perspective. It is wise to share these insights with the students. Discovering that the teacher can also learn from their views fosters student’s self-esteem, desire to learn, and willingness to share ideas. This in turn helps the teacher achieve the ultimate goal of education, e.g., teaching the students how to think.

To help college students develop critical thinking skills, we must increase our efforts to incorporate into college science courses a learning format, which teaches the student how to use scientific knowledge to critically analyze issues and arrive at justifiable solutions to problems. Described approach to teaching helps the student learn how to use deductive reasoning and parallel thinking to interpret the biological phenomena. Students also learn how to justify their interpretations by applying the acquired knowledge of scientific facts. Implicit in the format of described exercises is learning how to play an active role in decision making and how to work with peers in a collaborative manner. All of these skills will prove invaluable in the world the student faces upon graduation.

**Literature Cited**


