An Investigative Alternative to Single-Species Dissection in the Introductory Biology Laboratory

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Abstract: Dissections of single species (e.g., fetal pig) are a common student learning activity in introductory biology courses. Such dissections demonstrate location of anatomical parts and provide dissection practice but provide less opportunity for student critical thinking, numeracy and demonstration of the scientific method. A comparative anatomy lab was implemented over two years at a small, rural, private, liberal arts college. Students dissected their choice of five vertebrate species, mastered the location, function and gross evolution of the digestive and cardiovascular systems, and analyzed intestinal length and heart mass among sets of species. Instructors and students reported significantly more collaboration and reflective learning than in other exercises. The comparative approach highlights several evolutionary trends and created testable data at an equivalent cost to previous fetal pig dissections.

***Keywords**:* vertebrate evolution, comparative anatomy, quantitative data, hypothesis testing

INTRODUCTION

Undergraduate introductory laboratories often use dissection as an educational tool. Gross anatomical dissection is a useful skill for many biologists and reinforces the links between structure and function during the teaching of physiological and evolutionary concepts. Many published laboratory exercises regarding vertebrate dissection are simple explorations of terminology, fulfilling only the first cognitive domain of learning in Bloom's (1956) taxonomy. In addition, the model species of frog and fetal pig dissections are so common that students can claim college-level dissections are only review. Although dissections are new to some first year undergraduates, the value of repeating a single species dissection is lost to others. Some students surreptitiously avoid the dissection and instead memorize diagrams or photographs while others enjoy the dissection procedure but give little or no attention to mastering the biological concepts. Less common, but also disturbing, is when high-achieving students appear bored with re-memorizing from the same animal that they had seen previously. A need exists to improve students' dissection skills and mastery of anatomical terminology while engaging student creativity, hypothesis testing and critical thinking.

Vertebrate dissection exercises usually are limited to a few commercially available species that together provide a spectrum for anatomical comparison. Meuler (2008) described a multiple species approach that she tested with 15 students. She reported increased engagement after students answered qualitative questions and wrote a research paper based on two dissections per student pair over a four-week period. Our organismal biology course does not allow that much time for vertebrate anatomy or for the grading of that number of research papers. Instead we desired a more cost-effective alternative that stresses quantitative data analysis (a theme of the course) as well as evolutionary trends.

Here I introduce a comparative approach to dissection that requires critical thinking skills. Students choose which hypotheses to evaluate, and how best to combine and display their data. While students are required to learn all the same structures, they also choose which species to dissect. Some species (e.g., pigeon) have a highly specialized anatomy that might distract an introductory student from basic morphological trends. Some species are too small (anole), taken from overharvested populations (dogfish shark), or are too time-consuming (bowfin, turtle) or expensive (cat, rabbit) for large undergraduate laboratories. Therefore I chose perch, mudpuppy, frog, pig and mink as study specimens.

Experience in the first year showed that two class periods (three hours each) provided only enough time for students to learn two organ systems. Although students are exposed to the reproductive and skeletal systems, grades depend upon recall only of the digestive and circulatory systems. Previous laboratories all emphasize learning about hypothesis testing, data type and organization, and graphing and error, and this exercise shares these learning outcomes. Anatomical parts and functions are memorized outside of class without their instructor, with course time devoted towards dissection and concept application.

I designed a two week laboratory activity with two distinct experiences. In week one, students choose their specimen, and then (singly or in pairs) they dissect a species different from the one used by most of their peers, using customized dissection instructions. In the first week, all those students who have chosen to work on the same species work together and the instructor provides technical expertise in dissection skill only. The second week creates new student groups. Each new group contains at least one dissector of each vertebrate class examined. Each member of these new groups gives a brief oral presentation on anatomical function to the whole class, earning half of the dissection grade. Presentations are followed by the same groups exploring evolutionary trends across Vertebrata and then writing and evaluating hypotheses.

Students evaluate hypotheses from the digestive system as a class, and then choose from a variety of hypotheses about the cardiovascular system. The whole class first evaluates relative intestinal length by using student generated data and information on feeding ecology. Vertebrate intestine length varies greatly according to diet type, ranging from of 3-6 times the body length in carnivores to over ten times the body length in herbivores (Kardong, 2008). Students and the instructor use graphing to evaluate differences among mean relative intestinal lengths. Hypothesis writing and evaluation is usually helped by the few students already familiar with the relationship between diet and gut length. Less familiar to students is any trend in relative heart mass. Students are supplied with several ideas about cardiovascular evolution from which they can generate and test a hypothesis. I expected student groups to discover the large difference between fishes (whose relative heart masses range from 0.06-0.20% of body mass) and tetrapods (amphibian's relative heart mass = 0.46%, reptile's 0.51%, mammal's 0.59%; Farrell, 1991).

These comparative anatomy exercises were implemented over two years at a small, rural, private, liberal arts college. The exercise spans the last two labs (each three hours long) in an organismal biology class that covers physiology and evolution across kingdoms. Lectures concurrent with these laboratory exercises consist of basic vertebrate and invertebrate physiology on at least the digestive and cardiovascular systems. Here I report the exercise procedures, student data and outcomes as perceived by instructors and students. The complete laboratory, including preparatory guidelines, recommended sources for specimens, dissection instructions, natural history handouts, worksheets and data templates is available for use.

PROCEDURES

List of Materials (to supply 20 students)

Supplies required for weeks 1 and 2

- 2 American minks, 2 fetal pigs, and 4 each of mudpuppy, leopard frog and yellow perch. Except for the perch, all specimens' circulatory systems are double-injected.
- Dissecting supplies and equipment
- The class shares dissection atlases for each species
- Every student is provided with species-specific dissection instructions and a Natural History Handout detailing the classification, evolution and diet of each species.

Supplies for Week 1 (Dissection) only

- Microscopes showing digestive and cardiovascular system tissues and cells
- 2 pairs of blunt-nose pliers (required for fully opening mink oral cavity)
- Balances (0.01-2.00 g and 0.1-2.0 kg) and a 10 m tape measure

Supplies for Week 2 (Comparative Anatomy) only

- Articulated skeletons (3-4 each) and live representatives of bony fishes, amphibians, and mammals
- Multiple computers with compiled Week 1 data
- Statistical test results and graphs comparing relative intestinal lengths among trophic lifestyle, prepared in advance by the instructor

Pre-Lab Preparation

The students' pre-lab readings include introductions to dissection technique and to the available species. Instructors can survey student preferences for specimen type the week prior to dissection, and then combine the need for class time efficiency with respect for student opinion when choosing which student receives which species. Students working with fish and amphibians will finish dissections sooner than those working with mammals. Yet there usually are several students that are quite interested in dissecting mammals despite the extra time commitment. Prior to week 2, instructors compile data from all groups and laboratory sections into a single spreadsheet and email this to the students, along with a reminder of their oral presentation. In week 2, students read the Natural History Handout for each species. This handout (available from the author) summarizes the life history traits, ecological roles, diet (with per cent composition of each food type), interactions with humans and the geologic age of the specimen's class and family. Completion of readings is not evaluated, but the benefits of reading in advance are clearly demonstrated by the end of week 1.

Activity 1. Specimen Dissection (Week 1, 3 h)

An initial 15-20 m lecture by the instructor covers dissection ethics, specimen storage, dissection technique and anatomical orientation terminology. By the end of the lab period, the students need to report the sex, snout-vent length (total length for the perch), total mass, small intestine length and heart mass of their specimen. Students with ethical and/or religious objection to dissection can work with an online fetal pig dissection (Fleck *et al*., 2010). Instructors explain the oral presentation due at the beginning of Week 2. Because fish and amphibian dissections are completed earlier than mammal dissections, the instructor asks anatomy questions of these students.

Activity 2. You are the Expert (Week 2, 10 min preparation + 25 min X 2 groups = 1 h 10 min)

At the beginning of the second week, the class is split into two groups, each with an equal number of mammal, amphibian and fish dissectors. Groups are assigned randomly to present either the cardiovascular system or the digestive system, and are given 10 min to prepare. Each student is allowed 2 min to speak, and the students in each group must give their presentations in evolutionary order. Students are not only required to point out major anatomical features but are also responsible for naming differences between their specimens and whether these differences are typical of that class or are specializations (these are addressed in the specimen natural history handouts). Group presentations are graded for content, preparation, accuracy and usage of actual specimens.

Activity 3. Terrestrial Adaptations (Week 2, 30-45 min)

The class is divided into small groups (3-4 students), each with at least one dissector of fish, amphibian and mammal. First, each group member answers questions about the vertebrate class they dissected using articulated skeletons and live animals (which do not have to be the same species as those dissected). The seven questions are nearly identical but their answers may vary with the type of specimen. After answering the questions individually, students compare answers and, as a group, identify anatomical trends in vertebrate evolution (Table 1).

Activity 4. Comparative Anatomy and Heart Evolution (Week 2, 30-60 min)

The instructor demonstrates to the class how graphing can evaluate (but not statistically test) hypotheses. The class is asked to consider that perhaps relative intestinal length is constant, changes among vertebrate classes, or changes according to diet. After discussion the class is shown previously prepared histograms with error bars and statistical test results. The small groups from Activity 3 then

Table 1. Sample instructions and questions (Q) asked of each student. Answers (A) highlight evolutionary constraint or change across three vertebrate classes. Specimen-specific answers are separated by a backslash (/). Questions 1 and 5 demonstrate recall while questions 4 and 6 require application and analysis.

Observe an articulated specimen. Ask your instructor for help distinguishing true bone from cartilage and (soft rays / claws).	
Q1. Examine the placement of the (pectoral fin/forelimb) where it joins the pectoral girdle. Is the (fin/forelimb) emerging from the body laterally, ventrally, or in-between?	A: (laterally in fish / in between in amphibians / ventrally in mammals)
Q2. (tetrapods only): How many bones are in the middle toe?	A: Four
Observe a live specimen as it moves.	
Q3. Is the head capable of freely moving from side to side at the neck?	A: (no/some/yes)
Q4. From what part(s) of the body is most of the forward motion generated?	A: (slow movement from swaying of pectoral and caudal fins and fast movement from spine and caudal fin / hindlegs in frogs pushing up and forward / tail in mudpuppy / legs only in mouse)
Compare your answers to those found by other members of your group. Consider the differences and similarities across the vertebrate classes and answer the following questions as a group:	
Q5. Are the perch's fin rays homologous or analogous to tetrapod footbones?	A: analogous
Q6. Consider the vertebral column and how its muscles must be attached. When you compare aquatic to semiaquatic to fully terrestrial animals, what trends do you see in how forward motion was generated? How does this relate to flexibility and power?	A: Initially, the spine is the source of leverage for muscular power, then later is relegated to a balancing force for limbs.

Table 2. Student-generated anatomical data including relative intestinal length (small intestine length divided by snout-vent length) and heart mass (heart mass divided by rinsed specimen mass x 100%). Data are compiled from eight introductory biology laboratory sections taught in spring 2010.

	Relative Intestinal Length				Relative Heart Mass (%)			
Species	*N*	mean	range	SD	*N*	mean	range	SD
Yellow perch	17	0.85	0.33-1.41	0.35	17	0.21	0.13-0.67	0.13
Mudpuppy	18	1.23	0.55-1.93	0.39	18	0.47	0.11-0.83	0.20
Leopard frog	12	1.27	0.63-2.35	0.51	14	0.48	0.14-0.88	0.22
Domestic pig	14	7.38	3.05-11.85	2.50	13	0.84	0.55-1.37	0.22
American mink	12	3.31	2.29-4.67	0.65	12	1.12	0.64-1.57	0.28
All specimens	73	2.67	0.33-11.85	2.70	74	0.58	0.11-1.57	0.37

examine three ideas of vertebrate heart evolution. Heart size is presented as being influenced by the presence of limbs, a terrestrial lifestyle or endothermic metabolism. Each small group writes hypotheses for each idea as well as a null hypothesis, and then examines one hypothesis graphically. Each small group is graded on their hypotheses, figure and interpretive figure caption.

Assessment

I performed Kruskal-Wallis (K-W) tests for significant difference (α=0.05) in means among species groups using IBM SPSS Statistics 18 (SPSS Inc., Chicago IL). The K-W non-parametric test is less powerful than other statistical approaches but also has fewer assumptions (Sokal and Rohlf, 1981). Heart mass data were evaluated in a number of comparisons (e.g., by class or by aquatic lifestyle) and thus K-W *P* values were adjusted by Bonferroni correction (Sokal and Rohlf, 1981). Student learning and exercise logistics were evaluated by instructor opinion (gathered in weekly meetings) and then by anonymous student evaluations. At the end of the 2009 semester, students answered the same eight questions about each lab activity. Scores were adjusted to reflect a consistent scale (i.e., 5 = very positive, 1 = very negative) and a Mann-Whitney *U* test (Sokal and Rohlf, 1981) was used to detect a difference in mean student response between the comparative anatomy and the pooled responses for all other exercises pooled together.

RESULTS AND DISCUSSION

Comparative anatomy data on heart mass and intestinal length were generated successfully by students in 2009 and 2010. In the first year of implementation, data were problematic due to numerous student data entry errors. By 2010, data collation was supervised by the instructor and was restricted to sex, snout-vent length (mm), total mass (g), small intestine length (mm) and heart mass (g). A summary of data from 2010 only is in Table 2. Kruskal-Wallis testing revealed significant differences in mean relative intestinal length among dietary type (Figure 1a, $P < 0.01$), supporting the well-documented adaptation of increased intestinal length with increased plant ingestion (Kardong, 2008). After students were shown these results, they examined data regarding relative heart mass (RHM). Although the greatest differences in RHM occur between fishes and other vertebrates, student data showed significant differences ($P < 0.01$) among each species, class, aquatic lifestyle and thermoregulatory group (Figure 1b). Heart mass varies within each vertebrate class by activity level (Farrell, 1991), and it could be interesting to have more advanced students regress each species RHM by a metric of physiological activity.

Laboratory sections held a mean of 19.1 students (345 total students over two semesters, nine lab sections each semester), of which the majority were first year students. Each lab section was taught by one instructor and one (sometimes two) undergraduate teaching assistants. An anonymous survey administered after the first year of implementation revealed that a significant difference in student response between comparative anatomy (n = 156 responses among 8 questions) and all other lab procedures (n = 1872 responses). The mean score for all responses was 3.79 ± 0.89 for this exercise and 3.59 ± 0.00 for all other activities. The greatest differences were more positive responses to the questions “Collaborative work is a valuable part of this lab” (dissection = 4.20 ± 0.07, all other labs = 3.82 ± 0.02; $P < 0.01$) and “The lab provided opportunities for reflective learning” (dissection 4.14 ± 0.06, all other labs 3.93 ± 0. 20; $P < 0.01$). The lowest scoring question was “I felt rushed in this lab,” which was not significantly different from the other activities (dissection = 2.83 ± 0.10, all other labs = 2.77 ± 0.03; $P = 0.68$). Instructors reported that the laboratory’s primary weaknesses were the time required and student difficulty with graphing software, although these varied greatly among course sections. When compared to fetal pig dissection alone, instructors judged that the strengths of this revised laboratory were an increased critical examination of specimens, student investment and emphasis on evolutionary concepts.

These laboratory activities address all five cognitive domains of Bloom’s (1956) taxonomy.

The oral presentation activity requires students to master two organ systems as students cannot know in advance which system, and which portion of that system, that they will speak on to their peers and their instructor. The only materials allowed as visual aids are the specimens, meaning that students must interpret an actual specimen instead of recognizing and listing parts from a photo atlas. The graded portion of Week 1 therefore involves both knowledge and comprehension. Application of knowledge and analysis of new data are performed in the comparative anatomy portion (Table 1). The students infer evolutionary trends and are then presented with a novel example of comparative anatomy hypothesis evaluation. The students must work in groups to manipulate a raw dataset by making numbers comparable (calculating the relative heart mass) and separating it into appropriate categories (e.g., homeotherms vs. poikilotherms). These higher-order modes of learning are evaluated by examining student-generated hypotheses and graphs. Grading of the figure caption involves assessing students on their ability to evaluate, the most complex cognitive domain in Bloom (1956). Instructors noticed more evaluation than this, however, as students conversed and even argued about trends in anatomy and evolution.

The fetal pig is a common and appropriate choice for learning anatomy, but a single species dissection may not allow students to visualize evolutionary trends or practice meaningful data collection and interpretation. The strength of a comparative anatomy approach is the emphasis of differences resulting from evolutionary adaptation. Such differences may lead to students having evaluative experiences, such as determining the sex of non-mammals, or defining the beginning and endpoints of the perch heart or the small intestine. In the latter case, the ancestral aquatic habitat of fishes and amphibians meant little need for water reclamation or fecal storage and thus these classes lack a true large intestine. Similarly, the boundary between large and small intestine in the carnivorous American mink is indistinct at best. Students asking for a definitive answer are directed to consider the adaptations involved and then trusted to make their best evaluation. Evaluation was extended to numerical literacy as well, as students were surprised that trends could still be evident despite the presence of some investigator error. The subsequent questioning of when and how to trust data led to better interpretive sentences. Such learning outcomes are made possible by the simultaneous dissection of multiple species.

As with many laboratory activities, the major limitations of dissection are money and time. The cost of using multiple species is equivalent to or actually less expensive than providing a fetal pig to students working in pairs. A disadvantage is in taking up two laboratory sessions, but this is not a problem for our course considering the lecture time spent on vertebrate evolution and physiology. The loss of attention to other systems results in less recall practice for the students, but instructors have agreed that they prefer the greater depth of knowledge provided by the comparative approach.

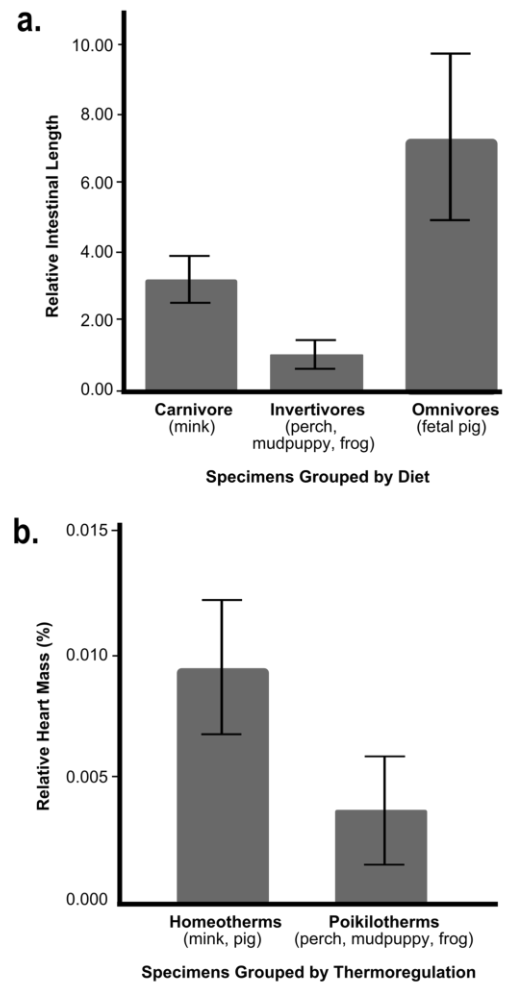

Fig. 1. Comparative vertebrate anatomy histograms (error bars represent a single standard deviation) on intestinal length (instructor-generated, top) and heart mass (student-generated, bottom). The instructor uses intestinal length to demonstrate how to graphically evaluate a hypothesis by combining specimens into categories before students generate their own heart mass graphs.

If more than two laboratory sessions can be made available, then other systems with other investigatory activities can be created. Additional exercises written, but not continued into the second year due to time constraints, included examinations of the reproductive, urinary and nervous systems with graphical evaluations of brain mass and kidney volume. The exercises could be expanded to include a basal vertebrate (lamprey) or a true herbivore (although rabbits are currently prohibitively expensive). Another obvious expansion of this activity is including invertebrates, but this would necessitate less emphasis on readily visible homologies. A third direction for improvement is in teaching numeracy. If time allows, the data generated can be explored by statistical testing.

Even without such modifications, course instructors and students appreciated the small group work, peer-to-peer learning and independent investigation. The exercise sacrificed evaluating student mastery of some systems, but did require in-depth knowledge of the digestive and cardiovascular system as well as the scientific method. The class dissected five species at nearly the same cost as our previous fetal pig activity, and many students appreciated choosing their species. The comparative approach to dissection demands greater self-reliance for recall, allows more room for student creativity and can facilitate a more critical understanding of anatomy, evolution and the scientific method.

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