

# Using Independent Research Projects to Foster Learning in the Comparative Vertebrate Anatomy Laboratory

Michael J. Ghedotti, Christopher Fielitz\*, and Daniel J. Leonard

Department of Biology, D-8  
Regis University  
3333 Regis Boulevard  
Denver, CO 80221-1099  
Email: mghedott@regis.edu  
Email: leona469@regis.edu

\*Department of Biology  
Emory and Henry College  
P.O. Box 947  
Emory, VA 24327-0947  
Email: cfielitz@ehc.edu

**Abstract:** This paper presents a teaching methodology involving an independent research project component for use in undergraduate Comparative Vertebrate Anatomy laboratory courses. The proposed project introduces cooperative, active learning in a research context to comparative vertebrate anatomy. This project involves pairs or groups of three students testing a hypothesis concerning variation of an anatomical feature among vertebrates and an oral or poster presentation that reports the results. The project requires both examination of anatomical descriptions in scientific literature and direct anatomical investigation of vertebrate specimens available in the laboratory. This project component has been used successfully at two schools, where it has increased student enthusiasm for the discipline, increased student interpretive skills, and better placed the course material within the context of science. Both faculty and student perceptions of the successes and difficulties of such a project are presented.

**Keywords:** vertebrate anatomy, active learning, cooperative learning, problem-solving, inquiry, research, hypothesis testing

The emphasis in undergraduate science education has shifted to active learning, cooperative learning, and problem solving (National Science Foundation, 1996; National Research Council, 2000; Carin and Bass, 2001; Miller et al., 2002). Ways to integrate these kinds of learning into collegiate laboratory courses in the more explicitly experimental branches of biology are usually more obvious. However, laboratory courses in disciplines such as anatomy traditionally focus on the memorization of names of structures, relationships among structures, and acquisition of dissection skills. This traditional emphasis makes ways to involve student inquiry less intuitively obvious.

Courses in comparative vertebrate anatomy are often difficult to teach because the material requires that students learn a complex terminology that is used in a variety of contexts (e.g., phylogenetic, functional, developmental). These contextual perspectives are critical if students are to understand vertebrate anatomy as a science and not simply a litany of names. This extensive anatomical terminology in anatomy courses, also leads students to consider vertebrate anatomy to be a biological field that is so well known that it is “beyond” active research and inquiry.

Suggestions have been proposed for increasing the problem-solving and deductive reasoning involved in human and comparative anatomy laboratories using

investigative exercises (Chang, 2000; Koprowski and Perigo, 2000), clinical case studies (Cliff and Curtin, 2000; Peplow, 1998), brainstorming (Geuna and Giacobini-Robecchi, 2002), and model building (Shigeoka et al., 2000). These strategies are useful in providing both a context for the knowledge attained in the course and developing problem-solving skills. However, in addition to helping students learn the material we also were interested in linking laboratory activities directly to the research experiences that sustain the discipline and provide students with a sense of personal ownership that has been shown to increase retention of content (Clark et al., 2000). Contrary to student perceptions, comparative vertebrate anatomy is very much a field of active research in which students can verify or nullify hypotheses through direct observations.

This paper presents a teaching methodology involving an independent research project component for use in undergraduate Comparative Vertebrate Anatomy laboratory courses. This project component has been used successfully at two schools, Emory and Henry College and Regis University, and both faculty and student perceptions of the successes and difficulties of project are presented. Two authors are faculty members (M.J.G. and C.F.) and one currently is a student who has taken the course (D.J.L.).

## INDEPENDENT PROJECT METHODOLOGY

### Overview

This project involves pairs or groups of three students testing a hypothesis concerning the variation in an anatomical feature among vertebrates and an oral or poster presentation that reports the results. Allowing students to work in pairs or groups provides students with a collaborative learning experience and reduces

the workload of this demanding project on each student. The project is not simply a literature review and requires both examination of anatomical descriptions in scientific literature and direct anatomical investigation of vertebrate specimens available in the laboratory.

### Selecting and Refining a Hypothesis

Early in the semester students begin by selecting an anatomical structure in which they have some interest. Students may choose any structure that is feasible to study within the limits of the facilities and specimens available, which is not explored in significant detail in lecture or laboratory. In discussing topics with students, telling them to pay some attention to function (or at least function as inferred from anatomical structure) likely will be helpful. The functional connection is especially important for structures such as muscles for which function can be clearly inferred from structure.

Once students select a structure, they propose a functional or evolutionary hypothesis to test. The hypothesis or question must be based on the students' knowledge of vertebrate relationships and anatomy, which will be somewhat limited early in the course. The instructor should help students develop clear hypotheses that can be tested with the specimens available for student examination. A proposed hypothesis could suggest that a structure will vary based solely upon function, based solely upon ancestry, or based upon some combination of the two. Hypotheses concerning development of structures typically are not reasonable given the specimens typically available. Students are encouraged to develop a more general hypothesis at the start that can be refined based upon some preliminary examination of specimens. (See Table 1.)

**Table 1.** Initial student hypotheses and the refined hypotheses developed after examination of specimens and the primary literature.

Initial Hypothesis	Refined Hypothesis
More active vertebrates will have more extensive coronary blood vessels.	Endothermic vertebrates, which typically have more active lifestyles, will have more extensive coronary vasculature and thus rely less upon oxygen from blood in the heart lumen than ectothermic vertebrates.
Tetrapod vertebrates that use their forelimbs for manipulation of objects will have more complex muscles in the forelimb.	Tetrapod vertebrates that typically move their manus with greater precision will have a more complexly divided forelimb musculature and these muscles will have longer tendons connecting to insertion points on the manus.
The ligaments supporting the liver in vertebrates will be most similar in closely related vertebrates regardless of how the vertebrates move.	Similarity in the position, number, and extent of hepatic ligaments in vertebrates will be similar among more closely related vertebrates and will not correlate with the type of locomotion utilized by the animal.

As in any scientific study, students need to begin by looking into what already exists in the published literature. Literature work should begin early in the semester when specimens in the laboratory are not yet ready for dissection. To introduce students gradually into the primary literature, they can start with the lecture textbook and laboratory manual. If the structure(s) being studied by the students is not mentioned, then students read about any associated structures. After reading what is available in course materials, students continue their research in the library. Instructors can facilitate this process by placing some relevant works on reserve. It is important to let the students know that, unlike in some other areas of biology that employ rapidly changing techniques, the publication date of sources is not as important a concern in anatomy. Gross descriptions of anatomy from the 1800s and early 1900s likely still will be useful and relevant. However, it is helpful to warn students that some older sources give different names to structures based on past naming conventions or older hypotheses of homology. We expect that students get their data concerning human anatomy from the literature since we did not have access to a cadaver lab at either of our schools and the literature on human anatomy is extensive. Readings in the scientific literature should help students begin the process of refining their hypotheses. Requiring that students turn in preliminary hypotheses with an annotated bibliography to the instructor for grading early in the semester helps ensure student complete the projects before the end of the semester.

In general, functional hypotheses will require students to do some research on the function or physiology of the organism or structure to be studied. For example, a study exploring the hypothesis that the liver will be more complexly lobed in endothermic organisms requires that students know about and can categorize the thermal physiology of all the specimens examined. Students would need to know, not only that birds and mammals are endothermic, but that birds usually have higher metabolic rates and body temperatures than mammals and also that turtles, lizards, snakes, and crocodylians typically have a higher metabolic rate and usually maintain body temperature higher than amphibians.

### **Initial Explorations**

A benefit of independent projects is that it makes it obvious to students that science in practice is a dynamic endeavor based on data. Students need to be encouraged to examine specimens as early as reasonably possible to start refining their hypotheses and determine if their hypotheses are testable based on the gross anatomical data that they can reasonably collect. It is often difficult to convince students to simply begin cursory examination of specimens and not begin an in-depth examination at the start as one

might run a series of planned experiments. This initial series of examinations is much like requiring students to perform a trial run of an experiment in molecular biology to refine the methods and ensure that the study is feasible (i.e., ensure that structures are visible, variable, and reasonable to examine given the methods available).

Students also need to determine which specimens they should examine. The best answer to the question “how many do I need to look at?” is “As many as you possibly can.” However, the anatomical structures of some organisms will be more important in addressing the hypothesis. If the student’s hypothesis concerns the correlation of a type of structure with a specific function, then the implication is that the similarity is due to function **NOT** due to ancestry. Therefore, finding two or more members of a closely related group that have differing function will be important data to use for supporting or rejecting the hypothesis. Conversely, if the student hypothesis concerns the correlation of a type of structure with ancestry, not with function, examining a range of organisms with different degrees of relatedness and different function would be needed for supporting or rejecting the hypothesis.

### **Gathering Data**

The gathering of data takes a significant amount of time and we arranged for students to have access to the laboratories outside of the class period. Students need to examine as many species and individuals as possible. Any hypothesis about anatomical evolution requires examination of more animals to be reasonably supported (or rejected). It is a good idea to remind students that anatomical structures often vary within species. Looking at a single cat does not necessarily provide a good base of knowledge concerning the anatomy of this species. We required student to keep a lab notebook for gathering data including sketches and prose descriptions. Students were told to specifically do the following:

- 1) describe the features of your structure that are relevant to the hypothesis being tested. It is not uncommon for students to have to re-examine specimens after looking at other specimens. Anatomists’ perspectives often change after observing how a structure varies.
- 2) measure each specimen’s size using standard anatomical measurements
- 3) identify each specimen's sex and its reproductive condition, sexual maturity or what stage of sexual activity it is at (e.g., pre-spawning female with ovary full of ova).
- 4) indicate the anatomical preparation and preservation of each specimen (e.g., double injected and preserved in Carosafe™).

- 5) indicate any individual peculiarities of each specimen, such as any damage or inferred pathology.

Students need to be cautioned that when dissecting specimens they must do as little damage as possible. If students need to dissect a bilateral structure, then they should be instructed to dissect only one side leaving the other intact. For reasons of economy and responsible use of specimens, we had each specimen examined by all the students who are studying its various anatomical features and required that students discuss any removal or destructive dissection with the instructor before proceeding.

## **DRAWING CONCLUSIONS**

Students then need to interpret their many observations both to address their hypotheses and to generally understand what they have observed. We suggested the following to students.

1. Arrange rough drawings, descriptions, or summaries of the organs or structures of various organisms in a table with organisms grouped taxonomically.
2. Arrange rough drawings or very short descriptions of the variable organ or structure along the top of the phylogenetic tree provided in class.
3. Arrange rough drawings, descriptions, or summaries of the organs or structures in various organisms in a table with organisms grouped based on pertinent qualities mentioned in your hypothesis. (Physiology, Diet, Function, etc.)
4. Consider what anatomy would be intermediate between the anatomical forms you saw in the species you examined. Would these intermediates be functional?
5. Consider how each type of organ or structure would develop.
6. Consider the natural history/ecology of the organisms examined and how that natural history would affect the functioning of the organ or structure.
7. Remember that the flexibility, texture, and especially the color of structures can be altered by the method of preservation and injection used.

Students can then use their data to support or reject their hypotheses. Students should be reminded that a single conflicting datum is enough to reject a hypothesis.

## **PRESENTING RESULTS**

Students should present their results in some format to the class. This allows students to see what other students have learned and provides a real impetus for students to synthesize what they have learned. We have used both scientific poster sessions and talks

involving visual aids. In both cases students are expected to answer questions about their research. The requirement that two (or more) students work together gathering data and producing a final presentation fosters the development of group skills and takes some of the pressure of the presentation off individuals. Opening the final presentation session to the academic and outside community gives the students a chance to illustrate their accomplishments and provides another incentive to take the whole process seriously. A digital camera is particularly useful, but not absolutely necessary, in allowing students to clearly show the structures they studied without spending a large amount of time illustrating.

## **PROJECT BENEFITS**

### **Direct Project Benefits**

A direct benefit of this type of project is that students come to understand one anatomical system in significant depth. The volume of material that is typically covered in a comparative vertebrate anatomy course means that students do not usually develop a comprehensive understanding of any single anatomical structure. This project provides students with some understanding of the overall complexity of vertebrate anatomy. Occasionally, students even identified errors or omissions in dissection guides. Independent-inquiry based projects in this instance and others clearly provide students with a sense of ownership of the material (Davis, 2002). A substantial benefit is the level of pride that the students take in their primary knowledge of “their” structure that has been shown to increase student retention of material (Clark et al., 2000; Rao and DiCarlo, 2001).

The project provides students with anatomical skills in dissection and examination of specimens. Repeated manipulation and examination of specimens result in students being more comfortable dealing with vertebrate tissues and organs. Students beginning the project may have trouble seeing variation or finding “their” structures. However, by the end of the project they are comfortable with the dissection and are able to recognize the types of variation that are anatomically significant.

### **Indirect Project Benefits**

One of the most satisfying benefits of the project is the realization by students that anatomical inquiry is a science based on observation that can support or reject hypotheses. Students also quickly realize that dissection manuals are not the final authorities and that there is much that currently is not known about the anatomy of vertebrates. By directing their research projects to areas of interest, students also became aware that vertebrate anatomy is relevant outside of the classroom. For example, students interested in pursuing graduate work in physical therapy chose studies of muscle or ligament variation.

As in most independent projects in courses, students developed an intimate understanding of how scientific inquiry proceeds. However, a particular benefit to this approach in a comparative anatomy course was the students' increased familiarity with anatomical terminology that clearly helped the students to be more comfortable than the more traditionally taught comparative vertebrate anatomy material. The projects also fostered an understanding of why fields like comparative vertebrate anatomy need to have such a complex terminology. The students needed precise terms to convey their results to each other as their projects progressed. Interestingly, for some students studying musculature, their learning was clearly extended beyond the classroom and into their daily lives when they went to the grocery store to purchase additional specimens for their study.

### **Project Concerns**

One significant concern about instituting an independent project component to the comparative vertebrate anatomy laboratory was that it reduced the amount of specific content that can be covered. Like Chang (2000) we had to reduce the laboratory coverage to incorporate inquiry activity into the course, and we chose to decrease the time spent on overall musculature, focusing more on the anterior musculature. We did not consider this reduction to be a serious loss because of the benefits cited above.

Another significant concern is the workload involved in an independent project. Independent projects require a significant time investment on the part of students and the instructor. This does not differ from independent projects instituted in other areas of biology. However, the types of observations necessary in an anatomical study usually require more time than typically is available in one or two laboratory periods set aside for the project. An anatomical project is not like an experiment that can be planned to start and stop at very specific times. It was occasionally difficult to effectively convey to the students the need to start early and that anatomical data require checking and re-checking. When including a project like this, the course needs to be adjusted so that too many demands are not placed on the students at the same time. A comparative vertebrate anatomy independent-project also requires some additional planning. Students need safe access to laboratories and specimens, often outside of class time.

Instructors need to purchase specimens of additional species for student examination. The traditionally studied dogfish sharks (*Squalus acanthias*), mudpuppies (*Necturus nebulosus*), and cats (*Felis catus*) are useful in the independent projects but they are not sufficient for most students' projects. Instructors should buy one or two individuals of a variety of species, many of which are much less expensive than cats. Some examples used include freshwater dogfish (*Amia calva*), perch, turtles,

American chameleons (*Anolis* sp.), snakes, pigeons, chickens, rats, rabbits, and minks. If the school is located in a rural area, students can be encouraged to bring in road kill, provided that the instructor has obtained and distributed copies of the proper permits and there is refrigeration for the specimens. Fetal pigs are not as highly recommended because of their earlier stage of development which means that they are less directly comparable to adult specimens. Students initially complained that they had no "talent" in making sketches of their observations. Digital technology such as a digital camera and microscope attachment can be employed. This allowed the students to document their work and alleviated some of the worries that the students had concerning illustrations. However, it is always valuable to have students sketch some part of the structure. Sketching forces close observation and encourages kinesthetic learning.

### **ASSESSMENT**

Evaluation of the independent research project was informal involving written course evaluations and individual student interviews. Generally, students considered the independent project to have been a valuable experience that contributed to their knowledge and appreciation of the discipline of vertebrate anatomy. The most frequently cited student concerns were centered on the amount of work required to complete the independent project while still being held responsible for learning much of the "typical" comparative vertebrate anatomy laboratory content. Students usually suggested a reduction of the "typical" material as opposed to elimination of the independent project. The instructors clearly noted an increase in student enthusiasm and a reduction in complaints about the complex terminology of anatomy. This was particularly noticeable in students who were doing poorly in either the lecture, or on lab exams that required memorization of structures. The instructors were also satisfied that students were able to recognize vertebrate anatomy as a field, like other fields in biology, which is based on testing assumptions using empirical evidence.

### **CONCLUSIONS**

An independent research project component implemented in undergraduate Comparative Vertebrate Anatomy laboratory courses at Emory and Henry College and Regis University was successful at actively engaging students in the field of comparative vertebrate anatomy as a science. Although implementing such a project does require time, consideration, and organization on the part of the faculty member and the students the benefits of such a project are tangible. The project engaged students as scientists, honing their interpretive skills as well as their technical anatomical skills. In addition, the

project placed the entire comparative vertebrate anatomy course within the larger context of science at a time when courses in anatomy are looked at by students and sometimes administrators and other faculty as less “scientific” than more classically experimental disciplines. We hope that others will implement similar research-based projects in comparative vertebrate anatomy courses to ensure that anatomical disciplines do not get “left behind” as

science education increases in its emphasis on active learning, cooperative learning, and problem solving (National Science Foundation, 1996; National Research Council, 2000).

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