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

Michael J. Ghedotti, Christopher Fielitz*, and Daniel J. Leonard IV
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 in a Comparative Vertebrate Anatomy course. 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 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.

Key words: Vertebrate anatomy, active learning, cooperative learning, problem-solving, inquiry, research, hypothesis testing

INTRODUCTION

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 learning strategies into collegiate laboratories are fairly obvious in the more explicitly experimental branches of biology. However, laboratories 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 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. The extensive anatomical terminology in anatomy courses, typically leads students to view comparative anatomy as a biological field that is so well known that it is “beyond” active research inquiry.

Suggestions have been proposed for increasing the problem-solving and deductive reasoning involved in human and comparative anatomy laboratories by 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 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 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. Faculty and student perceptions of the successes and difficulties of project are presented. Two of the authors are faculty members (M.J.G. and C.F.); whereas, the third is a student who has completed the course (D.J.L.).

INDEPENDENT PROJECT METHODOLOGY
Overview
Groups of two or three students test a hypothesis concerning the variation in an anatomical feature of vertebrates and give an oral or poster presentation of their 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. This project is not just a literature review, but it 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 their project 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. They should attempt to choose a structure that 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 to them in making their choice. The functional connection is especially important for structures such as muscles for which function can be clearly inferred from structure.

Once students select their structures, 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 concise and relevant 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 usually 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.)

As in any scientific study, students need to begin by looking into what exists in the published literature. Literature review should begin early in the semester before specimens in the laboratory are available for dissection. To introduce students to the primary literature, start them with the lecture textbook and laboratory manual. If the structures being studied by the students are not covered, they should read about functionally or physically associated structures. After reading what is available in course materials, students should continue their literature search in the library. Instructors can facilitate this process by placing some relevant works on reserve. It is important to inform students that, unlike in some areas of biology that employ rapidly changing techniques, the publication date is not as serious a concern in anatomy. Gross descriptions of anatomy from the 1800s and early 1900s will likely still 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 students will 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 fortunately the literature on human anatomy is extensive. Reading the scientific literature should help students refine their hypotheses. Requiring students to submit a preliminary hypothesis with an annotated bibliography early in the semester permits the instructor to make suggestions, which will be useful to the students and helps them to stay on schedule with their research.

In general, functional hypotheses will require students to do some research on the function or physiology of the organisms 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 need to know that birds and mammals are endothermic, and that birds usually have higher metabolic rates and body temperatures than mammals. In addition, they should know that turtles, lizards, snakes, and crocodilians typically have a higher metabolic rate and maintain a higher body temperature than amphibians.

Initial Explorations
A benefit of independent projects is that it makes it obvious to students that science is a dynamic endeavor based on data. Students need to be encouraged to examine specimens as early as reasonably possible to further refine their hypotheses.
and determine if they are testable based on the gross anatomical data they can reasonably collect. It is often difficult to convince students to simply begin by examining the structural aspects of their specimens. Because most biology students in our classes were more familiar with experimental biology, they were more comfortable beginning examination of all aspects of their specimens at once similar to running a series of planned experiments. We found that it was important to explain to students that the initial series of examinations is required for the same reason that molecular biologists perform trial runs, to refine the methods and ensure that the study is feasible. In an anatomical study the initial examination ensures that structures are visible, variable, and possible to examine given the methods available.

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

<table>
<thead>
<tr>
<th>INITIAL HYPOTHESIS</th>
<th>REFINED HYPOTHESIS</th>
</tr>
</thead>
<tbody>
<tr>
<td>More active vertebrates will have more extensive coronary blood vessels.</td>
<td>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.</td>
</tr>
<tr>
<td>Tetrapod vertebrates that use their forelimbs for manipulation of objects will have more complex muscles in the forelimb.</td>
<td>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.</td>
</tr>
<tr>
<td>The ligaments supporting the liver in vertebrates will be most similar in closely related vertebrates regardless of how the vertebrates move.</td>
<td>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.</td>
</tr>
</tbody>
</table>

Gathering Data

The gathering of data takes a significant amount of time. This may require students to have access to the laboratories outside of the class period. Students need to examine as many species and individuals as possible. To support or reject a hypothesis about anatomical evolution requires examination of a large number of animals. 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 recording data, which was to include 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 something varies.
2) Measure each specimen’s size using standard anatomical measuring techniques
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 in dissecting specimens they must do as little damage as possible. If students need to dissect a bilateral structure, they should be instructed to dissect only one side leaving the other intact. For reasons of economy and responsible use of specimens, we required each specimen be examined by all the students who needed to study the various anatomical features and required. Students were required to discuss any removal or destructive dissection with the instructor before proceeding.

**Drawing Conclusions**

Students will need to interpret their many observations 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 of various organisms in a table with organisms grouped on the basis of pertinent qualities mentioned in your hypothesis (physiology, diet, function, etc.).
4. Consider what anatomical form 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 could have developed.
6. Consider the natural history/ecology of the organisms examined and how that natural history would affect the functioning of their 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 may be 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 motivates students to synthesize what they have learned. We have used both scientific poster sessions and oral presentations 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 reduces the pressures of the presentation. Opening the final presentation session to the academic and outside community also gives the students a chance to demonstrate their work and knowledge. 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 preparing illustrations.

**PROJECT BENEFITS**

**Direct Project Benefits**

A direct benefit of this type of project is that students come to understand an anatomical system in significant detail. The volume of material that is typically covered in a Comparative Vertebrate Anatomy course often results in students not developing a comprehensive understanding of individual anatomical structures. This project provides students with an appreciation and some understanding of the overall complexity of vertebrate anatomy. Occasionally, students even identified errors or omissions in dissection guides. Independent-inquiry based projects clearly provide students with a sense of ownership of the material (Davis, 2002). An additional benefit is the level of pride that the students take in their primary knowledge of “their” structure; this has been shown to increase student retention of material (Clark et al., 2000; Rao and DiCarlo, 2001).

The project requires students to utilize anatomical skills in dissection and examination of specimens. Repeated manipulation and examination of specimens result in students becoming more efficient at and comfortable with dealing with vertebrate tissues and organs. At the start of the project, students usually have difficulty seeing variation in or even finding “their” structures. However, by the end they are comfortable with both dissection and recognizing the types of variation that are anatomically “significant.”

**Indirect Project Benefits**

One of the most satisfying benefits of the project is the students’ realization that anatomical inquiry is a scientific activity, based on observation that can support or reject hypotheses. Students also quickly realize that dissection manuals are not the ultimate authorities and that there is much that is not known about the anatomy of vertebrates. By conducting their research projects in 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 with most independent projects, students developed an increased understanding of how scientific inquiry proceeds. However, a particular benefit to this approach in a comparative anatomy course is the students’ increased comfort with anatomical terminology. This clearly helped the students to be more comfortable than with the more traditionally taught comparative vertebrate anatomy material. The
projects also provide 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. Interestingly, for some students studying musculature extended their learning beyond the classroom and into their daily lives. This was evident when several went to the grocery store to purchase additional specimens for their project.

**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. We chose to decrease the time spent on posterior musculature, focusing on the anterior musculature, and/or peripheral neuroanatomy, focusing on the central nervous system and cranial nerves. The fact that the anatomy of these areas in mammals was already covered in greater detail in other courses offered at our schools (Anatomical Kinesiology and Neuroscience) made the reduction of lab coverage most reasonable. The lecture components of these courses still covered these anatomical areas. We recommend that consideration of the anatomical components of other courses in the science curriculum and assessment of the laboratory time to be saved guide the selection of material to be excluded.

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 unlike projects in some other biological areas is not based on experiments of predictable duration, and requires repeated examination of specimens to check and double check observations. 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 the amount of work required is not unreasonable. A comparative vertebrate anatomy independent project also requires the scheduling of additional available time to permit students safe access to laboratories and specimens outside of class time.

Instructors need to provide specimens of other species in addition to the dogfish sharks (*Squalus acantbias*), mudpuppies, and cats. These traditional specimens are not sufficient for most students’ projects. Some examples of specimens found to be of value include freshwater dogfish (*Amia calva*), perch, turtles, American chameleons, 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, students use gloves when handling animals, and there is refrigeration for the specimens. Fetal pigs are not as highly recommended because of their earlier stage of development, which is less directly comparable to adult specimens. Students initially complained that they had no “talent” in making sketches of their observations. However, it is always valuable to have students sketch some part of the structure. Sketching anatomical structures forces close observation by students and encourages kinesthetic learning as hand movements in drawing are used to approximate the observed shape of the structure.

**Assessment**

Evaluation of the independent research project was informal and lacked statistically comparable quantitative measures. However, student feedback was gathered in an anonymous, open-ended, written course-evaluation questions administered at both schools at the end of the course and through informal discussion with individual students. In the course evaluations, 73.8% of students (31 of 42) indicated that the project was valuable and should be continued, 9.5% (4 of 42) indicated that the independent project was valuable but recommended that it not be continued because it required “too much” work, 7.1% (3 of 42) suggested that the project be discontinued with little elaboration, and 11.9% (5 of 42) gave no opinion on the project leaving the survey item blank. A large majority (83.3%) of 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. Most students who recommended discontinuing the independent projects recognized their value but were concerned about work load (9.5%). Comments included: “The hands-on learning was great in the projects but too much time was spent outside lab time.” “The independent project was fun and I learned a lot but I spent way too much time on it.” And “The project provided excellent ‘hands-on’ approach to anatomy, but the project took a lot of time. Don’t do it next time.” Some students recommended discontinuing the independent project (7.1%) without elaboration. Comments included: “Get rid of it” and “Don’t do independent projects.” The brevity of these responses does not allow further analysis. It should also be noted that the typical comparative anatomy course without an independent project also elicits comments about heavy work load and the benefits of the independent project were notable and recognized by most students.
The instructors clearly noted an increase in student enthusiasm for the course material 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, that is based on testing assumptions using empirical evidence.

CONCLUSIONS
An independent research component implemented in upper-division 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, organization, and additional work on the part of the faculty and students, the benefits of such a project are worth the effort. The project engaged students as research scientists utilizing their interpretive skills as well as their technical anatomical skills. In addition, the project served to help inform many students, faculty, and administrators of the scientific nature of comparative anatomy and its legitimacy as a research area. 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).

ACKNOWLEDGEMENTS
We thank the Biology Departments of Emory and Henry College and Regis University for support for the implementation of these projects.

LITERATURE CITED

Call for Reviewers
We are looking for persons who are willing to review manuscripts for *Bioscene*. We need reviewers for a wide variety of subject areas. Reviewers should be willing to provide in depth reviews and detailed suggestions for authors concerning revisions necessary to improve their manuscript for possible publication. Reviewers should be willing to provide a rapid turn-around time for the manuscripts they review. If you are interested in reviewing for *Bioscene*, please send an email that includes your phone number, FAX number, and a list of the areas for which you are willing to review to: William Brett, Chair of the Editorial Board, at lsbrett@scifac.indstate.edu.