Evaluation of the University of La Verne Biology Program Senior Thesis Exercise/Projects
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Objectives and materials reviewed for the evaluation.

The review is based on the reading and assessment of a sample of 17 senior exercises provided by Chair of Biology, Dr Jeffrey Burkhart. The most recent revision of the evaluation rubric used by the department faculty, and dating from 3/7/05, was used to assist in this evaluation. I was also provided with a copy of *A Manual for Biology Majors* which gives detailed instructions on the senior exercise.

Since I was given the primary charge of evaluating the senior assessment, this provides the major part of the report. However, since the goals of a senior exercise – or any other 'culminating activity' – inevitably complement those of the overall departmental program, and since strengths and weaknesses will relate at least in part to the biological foundation that students gain from their major, some additional closing comments are also given on the overall program structure and content.

Senior Exercise

While the quality of the senior exercises is very variable, it is generally impressive and the faculty should be commended for managing to assist in the design and mentoring of topically diverse and frequently technically or logistically ambitious projects. The best projects are as good as those that I have seen anywhere. That the faculty manage this while carrying such a high teaching load speaks to their dedication and expertise. As we all know, effective projects need to be tailored to individual student skills and circumstances, and require much ingenuity from the faculty, no matter how dedicated or independent the student. This challenge is exacerbated when the student pool is diverse in both academic preparation and professional goals. The value of the exercise for students is enhanced by the ability of the faculty to direct students into projects that transcend knowledge acquisition (as stated in the evaluation rubric) and give students a window into applied research, conservation, and/or enhanced biological understanding of the local San Gabriel watershed and terrestrial ecosystems.
Rather than focus on the strengths or weaknesses of particular projects, I will attempt here to identify and discuss the educational merits of a senior exercise, particularly the experimental projects that comprise the majority of those reviewed, and the extent to which these educational goals are being met based on this sample. In doing this, I recognize that not all of these goals may be deemed practical or of high priority by the department, and also that some of them may be addressed through other components of the biology curriculum. Nevertheless, I hope that by stating such goals as broadly and ambitiously as possible, key areas for possible improvement can be addressed for the faculty to consider.

In an ideal world...

An effective senior exercise can, and should, have diverse goals. It is an opportunity for students to take a bold step into exploring a question of their own design, apply their biological training to research this question, formulate explicit hypotheses and predictions based on the background research, and then to work with experienced faculty in designing appropriate methods and techniques to test their hypotheses. When experimental work has reached an appropriate stage, the data must then be analyzed – usually with appropriate statistical tools – in order to quantify the significance of the findings. Finally, the student should evaluate the biological meaning of the experimental results. This should involve comparative literature research, comparing the project findings with published work, and exposing the student to the process by which scientific findings are corroborated and refined, or frequently challenged and overturned. In an ideal world, the biology senior exercise would expose a student to all of these experiences. In so doing, it moves students beyond knowledge acquisition into the process by which new scientific understanding is advanced, and gives them direct experience in the assumptions, challenges and potential pitfalls inherent in that process. Though only a small cohort of any student pool may aspire to a research career, the ability to evaluate scientific literature with the hindsight that comes from personal research experience is a critical skill for any biologist.
Given this ideal, there are some areas in which the thesis provided are generally strong, and other areas that could be improved in most, if not all, of the theses. For want of a better or clearer way to itemize these, I will follow the rather prosaic approach of working through the main sections that comprise each experimental thesis. These comments pertain primarily, though not exclusively, to the experimental projects. Some subsequent thoughts are offered regarding the non-experimental theses.

Abstract

The content of the *Abstract* is very variable. Some theses give a summary of the introduction, closing with the project goals, while several summarize the goals and results but give no interpretation of the results, or summary of the main conclusions drawn. Very few provide a synopsis of the entire study, including topical overview, project goals, methods results and findings. It is not really apparent that students understand the function of the Abstract.

Introduction

Many of the theses do a commendable job of reviewing the general research area. Most of the introductions are well written and paraphrased, free from obvious instances of plagiarism or other stylistic inconsistencies, and clear. Two main deficiencies stand out. The first is the depth and extent of primary literature review. Most projects have appropriate reference citations (though a few are weak here) but in many cases the main sources are textbooks, general reviews, on-line articles, or reviews from "popular" science journals such as *New Scientist, Scientific American*, or even *National Geographic*. These may all have their place, but should not comprise the primary basis of a student's literature review. In part, I think this problem derives from the other main deficiency which is the derivation, articulation and stated rationale for the research question posed. Most of the theses give a general review, and then state their own experimental goals abruptly, without the literature review gradually focusing in on the specific topic under question.

This is always one of the most difficult areas for students to tackle. I suspect its difficulty and prevalence as a problem in this sample pertains to the limited time and understanding that students give to library use, using library search engines, and learning to read and distil the essential relevant information from primary research papers. This can all be done much more easily by paraphrasing a ready-distilled synopsis from a textbook or popular review article! Nevertheless, when it comes to reviewing and honing an explicit and often narrow research question, reviewing of the relevant primary literature is usually essential.

One way to help students transition from the general to the specialized literature review may be to have more explicitly stated expectations as to how the research question is developed and stated. I am not a particular advocate for teaching the 'scientific method' owing in particular to its devaluing of the most important component of discovery – exploratory research and information gathering. It also provides an artificial view of the way in which most actual scientific progress is made. Nevertheless, in order for students to conceive and articulate a clearly defined project that will be conducted over a defined period, it is extremely useful to have them develop a stated experimental hypothesis or hypotheses. The effective testing of a hypothesis involves the design of experiments that have explicit predictions if the hypothesis is true – that is, if the predictions are met, the hypothesis is supported, and if they are not met the hypothesis is rejected. While I stress that this will not always be a realistic or appropriate approach, it is one that, in my experience, can be adopted in most cases. Another benefit of this approach is that it facilitates the design of appropriate experimental treatments and controls, thereby helping students to design experiments that incorporate sufficient numbers of replicates and lend themselves to statistical analysis.

Materials and Methods

In most cases the *Materials and Methods* are clearly and appropriately described. The main recurrent shortcoming of this section is limited guidance for the reader concerning (i) how/why a particular methodology provides an appropriate test of the question, and (ii) how treatment groups and control groups are differentiated and the numbers of replicate studies in each case. There is a tendency for the *Introduction* to be followed by a detailed set of rather formulaic procedures. The connection between these and the stated objectives of the project is often left to the reader to fathom out!

In several cases, the suppliers of instrumentation were not given, names of materials not given or misspelled (Plexi Glass instead of Plexiglas), etc.

Results

The Results is inherently often the most complex part of a thesis, and presents some of the greatest challenges to the student. The *Results* and *Discussion* are the areas where, to me, the theses are weakest. The primary shortcomings in the *Results* concern data presentation and a deficiency in data analysis. Many students collected vast amounts of data, and in many cases these are apparently very interesting and contain valuable findings. However, in most cases, the data are presented in such a way that key results are not apparent. There is a tendency for students to present only raw data, and often in huge data tables.

Apparently the desire to show the amount of work that went into a project often trumped the desire to show off its findings! Where it is deemed necessary or appropriate to include raw data tables, they are usually better placed in an Appendix. A major skill in presenting results, and a very valuable one for students to tackle, is how to convey complex information in a simple format. Summary statistics and figures plotting means (±SEM) are excellent tools. Where figures present summary data in this way, the sample sizes in each group should always be given, either above the data points in the figure, or in the legend.

The other major omission of the results in most theses was statistical analysis. In some cases, such analysis was precluded by a lack of replicate treatments or appropriate controls for statistical comparison. While many students have a "stats phobia", most project data can lend themselves to simple parametric tests of association (correlation or regression), two-sample comparisons (G, Z or t-tests), or non-parametric Chi-squared treatments. It is very useful to have students think about how their proposed plan of data collection will lend itself to statistical analysis before a project is started. Since the program recommends that Bio 379 *Research Methods and Biostatistics* is taken in the junior year, this should give students adequate preparation in the concepts of probability and reasoning, and basic familiarization with statistical software. Every project should incorporate statistical analysis – no quantifiable confidence in the results is otherwise obtained. I would recommend that this area receive particular focus and that additional statistical instruction be provided, where necessary, so that students can incorporate some basic analyses into their research. Many of the theses examined present the experimental results, but give essentially no analysis. In some cases students mentioned "significant differences were seen…", either in the text of the results or in their *Abstracts*, but did no actual statistical analysis.

Discussion

The descriptive nature of the reported results in many of the theses, and probably some ambiguity among students as to what can actually be inferred from their results, tended to devalue the *Discussion*. In many cases, this section became little more than a concluding statement (some theses had a combined *Results and Discussion*) and did not do justice to the work and careful experimentation preceding it. In some cases the brevity of the *Discussion* was due to a lack of experimental results – something that can happen in any study. However, even in this case, there should be plenty of material for a student to incorporate in the *Discussion.*

As outlined in the general statement above, a good *Discussion* should include comparative literature review, assessing the project findings in light of what is known from other studies. If little is known for the species, system or study site in question, it is still valuable and appropriate to draw comparisons with similar but related species/systems/areas. For example, a study of groundwater contaminants could draw comparisons with other aquifers that have been studied, particularly those where similarities in geology, human impacts and catchment area provide a basis for similar inferences. A *Discussion* can pose further questions and directions for future research, and if a particular methodology proves unsuccessful it should discuss possible explanations. In the event of no results being obtained, it is still appropriate and a good educational tool to have a student speculate on the possible outcomes and evaluate their significance based on the current literature. Because of its brevity in many cases, this section tended to incorporate little literature research; this contrasts with peer-reviewed papers in biological journals where it would usually incorporate the most.

Bibliography

The standardization of format for referenced materials is good. The main deficiency in the bibliographies is the dependence on general literature and/or only a few key sources, rather than a more diversified literature base. The citation of references in the text of most theses was appropriate, although in a few cases students cited papers by topic or title (not by author), or cited page numbers which are normally omitted.

Non-experimental theses

Only two obviously non-experimental theses were included, and one of these was very weak. It was not clear from these, or from the student manual, whether the format or approach of a non-experimental thesis is standardized in any way. While there are possible benefits to a flexible approach, it would seem optimal to aim for a thesis plan that incorporates as much of the experimental thesis components as possible, even to the point of using existing published data as a basis for some new analysis and comparative discussion. An approach that we use at Pomona College (and is also adopted by many other institutions) is to have students write a non-experimental thesis in the form of a grant proposal in which the generation of the experimental project, and its justification based on researched literature and methodology, is the main focus.

Collective Summary and Recommendations

The thesis show impressive strengths in student discipline and quality of scientific writing, in faculty-assisted project design and faculty mentoring, and in the quality and understanding of field and laboratory methods pertaining to each project. Many students are clearly excited by their senior exercises and have "taken their projects and run with them". Where is comes down to hard work and time devoted to data collection, students excel. The areas where the theses are weakest indicate not only general areas in which students have difficulty, but areas where they are likely to be intimidated: statistics, and library use. Setting clear expectations for all theses to include statistical analyses, and perhaps requiring some minimum number of original research papers to be cited, could help with this. At some level, improvements in these areas will depend on mentoring during the actual thesis. Many research topics will be exploring systems where much of the pertinent literature is in specialized symposium volumes or periodicals that may require inter-library loan access and assistance from faculty. Students can often be assisted in their (frequently fruitless) early attempts to gather good primary literature sources by giving them a short (re-)demonstration of the library search engines and showing them the value of using papers as sources for other related studies. Having students submit a bibliography including a specified (minimum) number of primary reference citations as part of their initial thesis contract is a good way to get students researching journals from the outset. Getting students to be comfortable with statistics is partly overcoming phobias, and partly a matter of multiple exposure. Introducing one or two simple statistical treatments in a freshman or sophomore lab course, then incorporating statistics widely among the upper-

level course labs helps. Reiterating the meaning of a null hypothesis and probability value, and the arbitrary designation of the alpha = 0.05 also works well, in my experience. Even if students have trouble with frequency distributions, probability theory and variance, just making sure that they understand the meaning of a null hypothesis and why a lower p value is more significant will enable them to realize the meaning of statistical results in published literature, and translate this to their own work. While ecologists usually depend heavily on statistics, and consequently incorporate them into their courses, many other biologists do not. This should not be the case since variance – real or experimental – pervades all experimentation. There is probably scope to incorporate statistics, at least minimally, into courses that have excluded them in the past.
The importance of deriving a primary hypothesis from appropriate literature review, and stating this explicitly with experimental predictions, is also something that can be taught repeatedly through example in both foundational and upper-level laboratory courses.

Many of the more minor problems in this sample of theses could probably be addressed quite effectively simply by providing students with a more detailed and explicit set of thesis guidelines. It would help students if these could explain the goals and appropriate content of each of the main sections in more depth. The guidelines for data presentation and analysis, and effective writing of the *Discussion*, in particularly, could be significantly expanded. In Pomona College we give students a 12-page set of thesis guidelines.

The Evaluation Rubric is apparently made available to students as well as to faculty. While its content is fine, it condenses all the real questions of scientific merit into the first section, and then has complete sections devoted, respectively, to Organization of the Written Document, Language Use, and Academic Integrity. Some of the questions in Section I are very broad and encompass multiple sections of a thesis, as well as both experimental and literature research. I fear that the very condensed evaluation of the science in Section I ("Integration and Inference") and the lengthy sections devoted to presentation and language use, may give students a misplaced set of priorities. Both for the sake of students, and for assisting the faculty in assessing real quality of the project, a shortening of sections II-V, and an expansion of Section I would help.

It appears that the experimental projects vary widely in the time devoted to actual field/laboratory research. Some comprise research executed entirely during a short field trip, while others are apparently the product of a full year of research, sometimes with prior summer research included as well. I do not know how credit is assigned, and how the assigned credit for a thesis relates to the graduation requirements, but this appears to be an area of some difficulty. Increasing the expectations for library research and data analysis could provide a way to achieve a greater degree of standardization of thesis work-load and time commitment while still allowing for high flexibility.

I am free to meet with the any or all of the biology faculty to discuss the senior exercise, and the points raised in this review. I would also be happy to provide copies of our own thesis guidelines, evaluation procedures, or other information that may assist in the department's assessment.