Integrative Biology Senior Thesis Guide

IB theses come from across the face of biology – from tropical ecology to medical immunology – so there is no one-size-fits-all protocol for producing the perfect IB thesis. Every area within biology approaches its science in its own way: a tropical ecology paper is distinct from a medical immunology one in many aspects of approach, content, style, and presentation. The most important guide to the process is therefore your mentor in your lab: if you are a tropical ecologist, they will school you in the ways of tropical ecology, and, if you are a medical immunologist, they will school you in the ways of medical immunology. Another important consideration is your audience: your thesis will likely be evaluated by OEB faculty with knowledge of, but no direct expertise in, your field. You should be careful therefore to explain your ideas fully and not to make the kind of assumptions you would make about your audience if you were submitting the manuscript to an in-field technical journal. Bearing in mind the diversity of theses and the differences among sub-fields, and also the nature of IB's thesis evaluation process, this document summarizes key areas of the IB thesis process.

The best way to get a sense of what's involved in an IB Senior Thesis is to check out past theses. Hard copies are on the shelves outside Andrew Berry's office (BioLabs 1082). A listing of thesis titles from recent years can be found here; contact James Poolner for pdf's of theses you're interested in looking over.

Most scientific research is collaborative: most students will be working as part of a team of graduate students and/or postdocs. Your thesis will probably in part therefore present pieces of work that are not entirely your own. When writing up, make sure to be absolutely clear about who did what. We recommend (see below) that you include an "Attribution of Work" section in your thesis in which you lay out in detail who did each component of the work. In addition, we recommend that you use the first person pronouns in a meaningful way: for example, "I" if you carried out a procedure solo, but "we" if you carried in out in concert with a colleague.

The first and most critical step in writing a senior thesis is to think about the people who will be reading and evaluating your thesis. Your thesis readers will include your PI and OEB faculty in related areas to yours but with no particular expertise in your area. Your challenge then is to present your work at the level that any scientist can understand: to strike a balance between over-explaining and under-explaining. You don't want to report on each and every experiment, each detail of each procedure. On the other hand, you don't want your readers to grapple with a conundrum a non-specialist has no hope of unraveling. Your job is to distinguish what is important to explain and what should be self-evident to an educated scientist.

Your senior thesis is a formal research report that summarizes your work. It should:

- review the relevant background in your field

- describe how your work fits into the larger scientific context
- clearly describe your data
- fully analyze and critique your results.
- discuss how future work should address particular issues or build upon your work.

As you write your thesis, you should keep in mind that *clarity is of the utmost importance*. In order to write very clearly, it is crucial that you always keep in mind the basic scientific question(s) that your work attempts to answer. These questions should be introduced and explained well in your Introduction. You should return to these driving questions in subsequent sections throughout the thesis, regularly reminding the reader how each result fits into your overall scientific goal.

THESIS TIMELINE

1. Your PI

IB encourages you to get involved in Life Sciences research in the area that most interests you. We are happy to support students doing research, for example, in remote field stations, or at Harvard Medical School, or at the Broad Institute, or at the Harvard School of Public Health. If you're working with a PI outside of the OEB Department, we require that you have an OEB faculty member as a "Thesis Sponsor." The idea is to find an OEB faculty member with interests closest to your non-OEB PI's; talk to Andrew Berry about this. We have this requirement because sometimes labs that are unaccustomed to working with undergraduates (eg at the Medical School) have little or no experience of the level of work involved for an IB thesis. Your OEB sponsor can help out on this.

2. Typically at least one summer in the lab or field

Thesis writers typically spend at least one summer working full time on their thesis (some will dedicate all three of their undergraduate summers to research), and that is normally their Jnr-Snr summer (though in the past students have, for example, done their research over their Soph-Jnr summer and done something else over their Jnr-Snr summer). Unlike some other concentrations, which require "Thesis Proposals" for submission and evaluation before the work starts, IB has no particular deadlines prior to your Snr Year. However, you will need funding for for the summer, and these deadlines are spread through the Spring Semester:

- Harvard College Research Program (HCRP)
- Herchel Smith
- Harvard Center for the Environment
- MCZ Grants in Aid of Undergraduate Research
- See also the general Life Sciences Research Funding page.

3. OEB 99r

OEB 99r is a course that may be repeated for credit (the "r") that allows you to get academic credit for in-term research. Note that you can do 99r even if you are not writing a thesis. Also, thesis writers are not required to do 99r; some people prefer to be funded to do their research (typically through HCRP's in-term funding program) and Harvard does not allow you to be paid and to gain academic credit at the same time. Most IB thesis writers, however, do two 99r's in the course of their Senior year: the Fall semester involves finishing up the work from the summer; the Spring semester is dedicated to writing up. In principle, you can do more 99r's, but we encourage people to do no more than two (i.e. to limit them to your Snr year) simply because we believe that there are plenty of other interesting courses you could be taking. 99r requires paperwork to be submitted by study card day, and it requires the submission of a written report in Reading Period. If you're writing a thesis, the thesis counts as your 99r report for your Snr Spring. OEB 99r is letter-graded by your PI.

4. Thesis Workshops

At intervals, during both the Fall and Spring Semesters, we will run a number of thesis writing workshops to talk about the process, and to provide a forum in which thesis-writers can exchange tips, guidance, etc.

5. January Term

January term in your Senior Year is an ideal opportunity to complete your research prior to writing up during the Spring Semester. As a thesis-writer, you qualify for free on-campus housing over the period, but you have to be sure to sign up for it (through your house).

6. One-page Thesis Abstract form

This is downloadable from the IB website and is due to James Poolner's office (BioLabs 1082) by **study card day of Spring Semester**. It is assumed that the abstract may evolve somewhat before you turn in your final thesis. We use your abstract to recruit appropriate faculty readers.

7. Writing Up

We encourage you to dedicate your Spring Semester to writing up, a process that unfailingly takes considerably longer than anticipated. If you are still doing experiments, you will have to make a decision

when to call them off so that you can focus on writing. Note that the completeness of the experiments can be a major difference between an undergraduate thesis and a doctoral thesis, and it is understood that undergraduates often are not able to fully complete the work they set out to do. Unlike other concentrations, IB does not impose deadlines for thesis drafts, but you should work closely with your mentor to establish a workable set of self-imposed deadlines. Remember: if you expect your PI and/or other mentors to read and comment on your work, you should give them plenty of time to do so.

8. Thesis Submission

One bound copy AND one complete digital copy of your thesis (in PDF format) are due in James Poolner's office (BioLabs 1082) by **5 PM on the day before Spring Break**. The digital copy may be emailed as a single pdf document to jp@mcb.harvard.edu (James will provide upload instructions if your file is too large for email) and must also arrive by 5 PM.

9. Grades

The evaluation process takes a while. You will receive notification of your grade along with a full set of reviews from your readers towards the end of the semester. Many students continue working on their projects during the second half of the semester, with a view, perhaps, to preparing a manuscript for publication.

THESIS GRADING

Your thesis is sent out for review by your PI and three other OEB faculty readers in areas as close as possible to yours. Note that these other readers may not be expert in the specific area that you have worked in; be sure, then, to write an introduction that places your work in its larger scientific context. All thesis readers are asked to provide narrative evaluations. Readers are given the option of reviewing anonymously or of identifying themselves. Typically, faculty treat these reviews in the same way as they would a paper under peer review, meaning that the critique may sometimes be unsparing. The readers' reports are reviewed by the OEB Undergraduate Committee, many of whose members have served in previous years, ensuring continuity in terms of consistency of grading from year to year. The Committee's job is to review the narrative reports from all the readers, and, based on these narratives, to assign the thesis grade (No Credit, Creditable, Praiseworthy, Excellent, Exceptional). Note: The thesis is primarily evaluated as a written work. Students receive credit for their laboratory performance in their grades for OEB 99r.

Thesis Grades

EXCEPTIONAL: This grade is reserved for truly outstanding theses. Mastery of difficult techniques is not in and of itself an adequate criterion for earning the Exceptional distinction; nor is the judgment that a particular thesis is publishable. Note (from the Honors Table) that “Exceptional” does not differ, in terms of Honors, from “Excellent.”

EXCELLENT: This grade distinguishes well-written theses that report scientific research of very high quality. The thesis should be without serious flaw in both the design and the execution of the project. Theses of this quality are often publishable.

PRAISEWORTHY: This grade distinguishes clearly written theses which reflect a very good effort. The result obtained may be publishable. Most theses are expected to fall into this category.

LAUDABLE: This grade acknowledges that a serious effort was made to test a good hypothesis. The rationale, methods, and results should be clearly described.

NO CREDIT: This grade is reserved for theses that do not meet the standards expected of an IB undergraduate thesis, either in the writing of the thesis or in the quantity and quality of research undertaken for the thesis. You do not have to submit a thesis in the IB concentration and "No Credit" is equivalent in determination of honors etc. to no thesis. If you are concerned that you may fall into this category you should seek the advice from Andrew Berry as to whether you should submit a thesis.

CONTENT OF THE THESIS

Apart from the College requirement of the Honor Code, IB has no requirements for what you put into your thesis. This is partly because different sub-fields within biology have different traditions and styles of presentation. However, here are some general guidelines.

Honor Code Page. A signed statement of the Honor Code page is required.

Suggested text:

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In submitting this thesis to the Department of Organismic & Evolutionary Biology in partial fulfillment of the requirements for the degree with honors of Bachelor of Arts, I affirm my awareness of the standards of the Harvard College Honor Code.

Name: _____

Signature: _____

The Harvard College Honor Code

Members of the Harvard College community commit themselves to producing academic work of integrity – that is, work that adheres to the scholarly and intellectual standards of accurate attribution of sources, appropriate collection and use of data, and transparent acknowledgement of the contribution of others to their ideas, discoveries, interpretations, and conclusions.
Cheating on exams or problem sets, plagiarizing or misrepresenting the ideas or language of someone else as one's own, falsifying data, or any other instance of academic dishonesty violates the standards of our community, as well as the standards of the wider world of learning and affairs.

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Title Page. Here is a sample title page. Students in the past, however, have departed markedly from this standard formatting, including, for example, images.

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[Title] (centered approximately 1/4 down the page)

A thesis presented by

[Name]

to

the Faculty of the Department of

Organismic & Evolutionary Biology

in partial fulfillment of the requirements

for the degree with honors

of Bachelor of Arts

Harvard University

Cambridge, Massachusetts

[Month and Year of Submission]

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Abstract. The Abstract should be a single paragraph and should not exceed a page in length. It should define clearly what is dealt with in the thesis and should (1) state the principal objectives and scope of the investigation, (2) describe the methods employed, (3) summarize the results, and (4) state the principal conclusions. Most of the abstract should be written in the past tense, because it refers to completed work. The abstract should never give any information or conclusion that is not stated in the thesis. References to the literature should not be cited in the abstract.

Acknowledgments. This section is reserved for you to thank and acknowledge individuals who may have been helpful to you during the thesis process. Some thesis writers like to combine the Acknowledgments and Attribution of Work sections.

Attribution of Work. In this section, you should clearly and simply state who did what portions of the project. You should explain which portions were done independently by you, which were done in collaboration with others, and what data others may have contributed. This is important! Readers are always keen to know what parts of a group project were truly the student's own.

Table of Contents. The table of contents should list, and give page numbers for, every section of the thesis.

List of Figures/Tables. List all tables and figures (including data figures, other schematics, illustrations, etc.) present in the thesis. Also list the page number where each can be found within the document. Any page devoted to a table or figure should be counted and numbered like all other pages.

Abbreviations. List all relevant abbreviations used throughout the text for the reader's easy reference. Any abbreviation listed here should also be introduced and spelled out the first time it appears in the text.

Introduction. The Introduction should present an overall framework for your research by reviewing the literature, discussing what is currently known about the particular subject (as well as perhaps how this knowledge may have evolved historically), identifying relevant questions or debates that exist in the field, and detailing the specific question/s that you investigate in the thesis. The Introduction often reads like a mini review article on your topic. It should be very obvious to the reader what specific scientific questions you aim to address with your work. If you introduce the background well, the reader should also understand why your specific work is an important and obvious next step for your particular field or laboratory.

You should end your introduction by clearly stating (or perhaps restating) your objectives and rationale for the thesis. This provides a starting point for the thesis and tells the reader what to expect in the forthcoming sections.

Throughout the introduction you should supply sufficient information to allow the reader to understand the forthcoming results without her/him needing to read previous publications. When in doubt, explain briefly. Include schematic figures or diagrams in your Introduction that illustrate the details you are introducing. If it is something crucial for the reader to understand, a figure is always a good idea. It improves your overall presentation and also helps the reader to focus on the important points they must understand for the remainder of the thesis.

Throughout the Introduction and all subsequent sections, you should include in-text citations of all relevant published work. References serve multiple purposes. Beyond their most important role in giving credit to previous work, references also serve as resources for the reader to learn where s/he might find

further reading on a particular subject. Be sure to include relevant reviews or even textbook chapters that you found helpful as you learned about your topic.

Materials and Methods. This section details how you conducted the work. Give enough detail so that the reader has an idea of how to conduct a similar experiment, but don't include the excruciating details of full protocols. For example, include concentrations or final dilution amounts, but do not explain step-by-step how to make your buffer. Use subheadings to help guide the reader through the Material and Methods section (e.g., "Tissue preparation"; "Imaging & Analysis"; etc.).

Results. This section comprises the body of the thesis. The Results section should be presented in an explicit, logical order, so that the reader will understand the purpose of each experiment. This section summarizes the data obtained and should describe the results in a matter-of-fact manner but not overly interpret them (which would be done in the Discussion). Rather than simply listing one experiment monotonously after another, walk us through your logic using key transition sentences that remind us of your underlying scientific questions. If you completed two unrelated projects, you may consider separate sections or chapters within the Results section. You may also include relevant experiments with negative or no results.

Figures. The visual elements in your thesis should be a mirror of the written elements such that either the figures or the text may stand alone to tell your story. In other words, you should ideally have a figure to visually represent each main result described in your text. Your figures, diagrams, and tables should be properly labeled, with descriptive figure legends and any sources acknowledged. Clear, well-labeled figures help significantly to impress readers with the overall professional presentation of your thesis. Figures and tables should be numbered in the order that they are cited in the text (for example, Figures 1-2 in the Introduction, Figure 3 in the Methods, Figures 4-11 in the Results, etc). Ordinarily, figures should be presented in portrait orientation with the figure legends accompanying the appropriate figures. We suggest that you dedicate a page to each figure and insert that page into the appropriate position within the text. We suggest that you do *not* embed the figure in the document using MS Word. (This can lead to a formatting nightmare for you.) You may instead choose to place the relevant figures together at the end of a chapter or section, although some readers prefer that figures appear within the text where they are relevant – check with your mentor to figure out what is appropriate in your field. The pages on which figures appear should be numbered in sequence with the text and appear in the Table of Contents and/or List of Figures.

Most figures should be prepared as multi-panel plates, as they appear in a typical journal article, rather than as single images. Individual panels in a plate should be consecutively lettered, and for all images for which it is relevant, a scale bar should be included in the figure and defined within the figure legend. All text within the figure should be large enough to be read easily. Where possible, figures should consist of black lines and lettering against a white background. Color should be used to differentiate or emphasize

specific features of a drawing, but only if scientifically necessary (i.e., needed to differentiate the different parts of the image, such as different lines in a graph).

In order to present a complete story, it is sometimes appropriate to include some minimal data conducted by another individual in the lab. Work done in collaboration with others or even by someone else may be included in your thesis, but *this must be acknowledged in the figure legend even if the appropriate researcher is also given credit elsewhere*. The reader assumes that all figure data presented are yours unless it is explicitly stated in the figure legend.

When creating/importing figures, make sure that they are at sufficiently high resolution to avoid any possible pixilation or blurriness.

Discussion. The discussion section should first of all summarize and analyze the results that you have presented. Also recapitulate your overall argument(s) presented in the Introduction as well as strengths and weaknesses, and address the theoretical issues that were used in approaching and analyzing the problem. You should also explain how you may have modified your view of the issues in the course of conducting the analysis. If your experiments did not produce significant or meaningful results, explain here your thoughts on why this might have occurred, and suggest how things could be done differently. Convince the reader that you have fully thought through and understand the implications of your work, no matter how individual experiments may have turned out. The discussion should place your findings into the larger perspective. It is the best section to demonstrate to the reader how carefully you have thought about your work and how sophisticated your thinking might be regarding its nuances and implications. Be sure to compare your findings to previously published results – are your data consistent with findings from other studies? Why or why not? Importantly, end with a section detailing further questions to be asked and directions for future study. Faculty readers will look specifically for a discussion of how future experiments may build upon or improve your work.

Conclusions. Some students add a section to pull things together at the end.

References. Factual statements and claims that you make throughout your Introduction, Methods, Results, and Discussion sections should be backed up by providing citations to relevant published work.

For references, you should use whatever bibliographic notation style that is normal in your field. Check with your mentor for recommendations.

Regarding in-text citation, please use the author-year method as shown in the first sample above. Do not use footnote or numbered format, which make things more awkward for the reader. Here are two examples:

Watson and Crick (1953) proposed that DNA formed a double-helix.
- or -
The nucleotide bases are on the inside of the double helix and the phosphates on the outside (Watson & Crick, 1953).

To simplify the citation process, we urge you to use an in-text citation program such as Endnote or Refworks, both of which can be downloaded online via Harvard. To read more about using these programs, visit http://guides.library.harvard.edu/cite.

All thesis writers should read this brief guide regarding citations: '*Guide to Using and Citing Sources When Writing in the Life Sciences'*: *http://tinyurl.com/LSCitationGuide*

THESIS FORMATTING AND STYLE

Length: How long should the senior thesis be? It should be as long as is appropriate for the subject: If it is too short, it will be impossible for the reader to see the importance and meaning of the work; the reader will not be able to discern if the student really understands the material, if the student sees the larger picture, or if the student really understands what story the experiments are telling. If it is too long, the reader will be bogged down in all extraneous material and will face the same problems in evaluating the work. As you write, consider a member of faculty with eight theses to evaluate: short is therefore good, but clarity of presentation is paramount. In general, the typical honors IB thesis is 40-60 pages, with figures, footnotes and diagrams, although this number is absolutely not a hard and fast rule.

Style: Your thesis should read like a professional scientific journal article, but – this is important – should be rather more discursive than a typical journal article. Remember that your readers are not in-field experts, as journal readers typically are, meaning that you should make more effort to explain in-field issues than you would if you were sending the manuscript to an in-field journal. It is not appropriate to describe your personal experience (outside of the Acknowledgements section) or to demonstrate your creative writing style. Use this opportunity to develop your own writing style – but write *clearly*. Committee members scrutinize the quality of the writing and editing. The thesis will be graded on the basis of content and writing effectiveness. Your grade will be undercut by inattentiveness to style, form, grammar, punctuation, spelling, and citations.

Active or passive voice? We prefer the active voice to the passive one. It's easier to read that way.

"I" versus "we"? Use "I" if you are referring to work done by yourself. Use "We" if you are referring to work done with others.

Copies/Binding: IB has no stipulations or requirements about how you bind your thesis. The printed copy is most commonly bound in spiral binding, which Kinkos, Staples, Gnomon, or Flash Print can do for a nominal fee. (These copy centers are very busy around the thesis deadline – plan a day or two ahead!) Staples even offers a service that allows you to email them a pdf and they will print and bind the thesis for you within a few hours. (If you choose to print the document yourself at the Science Center around the thesis deadline, be prepared to wait long hours for printers.) (Also beware: Copy centers like Staples etc. may charge you for color printing the entire document, even if it only contains a handful of color pages. Best is to ask them to print the whole document in black and white, then specify the few pages that need to be reprinted in color and inserted.) For binding, you may also purchase basic manual binders from CVS. You may wish to print and bind an extra copy for your own personal records or for your lab.

Formatting: IB has no requirements re paper, format, font, etc. But you should definitely be sure to number the pages. As you write, you should always be thinking of that over-burdened faculty member with a pile of theses to evaluate, including yours: be sure to lay things out in a way that is maximally reader-friendly.

HELP!

Don't hesitate to contact Andrew Berry berry@oeb.harvard.edu if you have any questions.

GOOD LUCK!